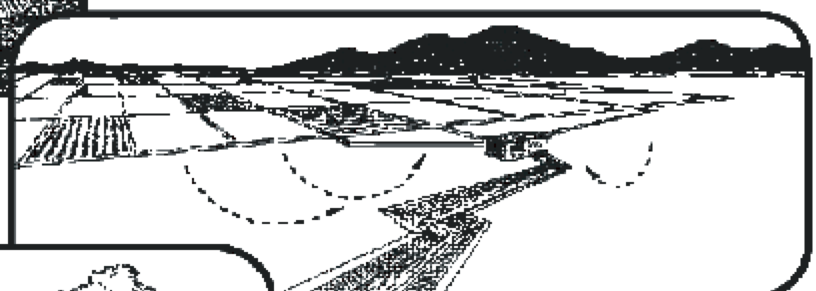
Effects of Selenium, Mercury, and Boron on Waterbird Egg Hatchability at Stillwater, Malheur, Seedskadee, Ouray, and Benton Lake National Wildlife Refuges and Surrounding Vicinities



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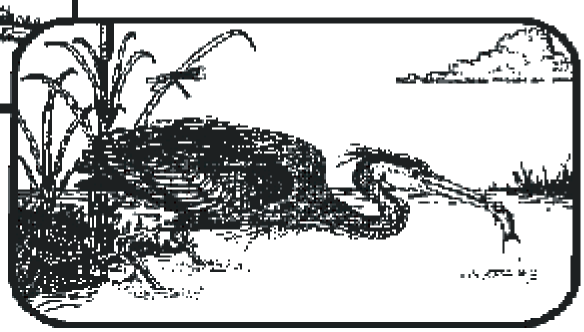

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By Charles J. Henny, Robert A. Grove, and V. Ray Bentley
USGS Forest and Rangeland Ecosystem Science Center

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

For additional information, please write to:

Dr. Charles J. Henny
U.S. Geological Survey
Forest and Rangeland Ecosystem
Science Center
3200 SW Jefferson Way
Corvallis, Oregon 97331

charles_j_henny@usgs.gov

To request copies of this report, contact:

Manager, NIWQP (D-6200)
Bureau of Reclamation
PO Box 25007
Denver, Colorado 80225-0007

Agricultural drain running into Ocean Lake, Wyoming.

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Abstract

Reproductive studies of birds were conducted at five National Wildlife Refuges (NWRs) and surrounding areas of Montana, Nevada, Oregon, Utah, and Wyoming in 1986, 1987, 1988, and 1989. These locations were all associated with agriculture and received agricultural drainwater from either surface or subsurface sources. Earlier reconnaissance investigations of drainwater contaminants were conducted at four of the five refuge locations. Our study evaluated concentrations of drainwater trace elements (selenium and boron) and mercury in waterbird and raptor eggs in relation to reproductive success and the incidence of abnormalities. The "sample egg" technique was used to relate egg residue concentrations from the sample egg collected to the success of the remaining eggs in the clutch. During the first year of the study, a large percentage of monitored duck nests were depredated. We subsequently used incubators (two eggs per duck nest) to eliminate the confounding effects of nest predation on reproductive success. However, duck nests with two eggs collected and placed in the incubator also continued to be monitored to evaluate success under field conditions. The field observations provided biologically important information about the nesting success of ducks and other waterbirds in the arid West, but the information was of limited use for contaminant evaluations. We relied upon published egg residue concentration criteria to evaluate the potential hazard, and in the case of duck eggs from the incubator, our hatch data supported the literature; i.e., duck eggs with 10 parts per million (ppm) selenium dry weight (dw) hatched at a lower rate than eggs with <10 ppm selenium.

In the Lahontan Valley, Nevada (including the Stillwater Wildlife Management Area [WMA]), only 0.4% of duck eggs and 0.7% of other waterbird eggs contained 6 ppm selenium, which is the lowest reported effect concentration for any species. Black-necked stilt (*Himantopus mexicanus*) eggs are the most sensitive to selenium. The degree to which nesting success was impaired by selenium toxicity was believed to be low in the valley in 1986-88. Our findings, based upon eggs collected during this study, were consistent with findings based upon water data collected by other investigators.

Waterbird eggs from the Lahontan Valley consistently contained mercury concentrations above the background value (geometric mean 0.50 ppm) used for this study. The mercury source was the upper Carson River, upstream from the Lahontan Valley, where mercury was used to extract gold and silver from ore mined in the Comstock Mining District (1859-1890). The incidence of eggs collected in the Lahontan Valley with 3 ppm mercury (effect concentration) was 5.5% for ducks and 13.5% for other waterbirds. These were the highest mercury percentages reported during this study. Only 1 of 220 eggs (0.5%) contained boron above 22 ppm (an upper concentration associated with normal hatchability of mallard [*Anas platyrhynchos*] eggs); it is doubtful that boron negatively influenced hatchability of many eggs for any bird species. Only one embryo deformity was found in the Lahontan Valley. The drainwater contaminant concentrations fluctuated among locations, species, and years. The year-to-year fluctuations were most prominent for mercury. For example, mercury concentrations in the eggs of American coots *(Fulica americana)* at Humboldt/Toulon, which is located outside the Lahontan Valley boundary, fluctuated as follows: geometric mean 1987, 0.19 ppm; 1988, 0.17 ppm; 1996, 3.19 ppm. A better understanding of drainwater pollutants and mercury is needed to predict residue concentrations in eggs in relation to water conditions that rapidly fluctuate in the Great Basin and other portions of the arid West. Perhaps contaminant-related problems may occur infrequently (only a few years) during a decade or water cycle (this study was limited to 1 to 3 years at each site, with some additional data available from other studies).

At Malheur NWR, Oregon, no duck eggs or other individual waterbird eggs contained 6 ppm selenium, only one egg (0.5%) contained 3 ppm mercury (a northern harrier [*Circus cyaneus*]), and no eggs contained >22 ppm boron. No deformities were found in 1986-87.

In 1988, at Seedskadee NWR and surrounding locations in western Wyoming, 4.0% of the individual eggs collected contained 6 ppm selenium (these were the eggs of three American coots, one black-crowned night-heron [*Nycticorax nycticorax],* and one double-crested cormorant [*Phalacrocorax auritus*]). None of the duck or eared grebe (*Podiceps nigricollis*) eggs contained 3 ppm mercury, but 0.8% of the other waterbird eggs contained 3 ppm mercury (the egg of a double-crested cormorant). No deformities were found in Wyoming. No boron concentrations above 12 ppm were found in eggs from Wyoming or Utah. In northern Utah, at Ouray NWR and Stewart Lake, selenium was 6 ppm in 45% of the eggs and 10 ppm (effect concentration for ducks) in 30% of the eggs. Our findings agree with other published information from these sites. A mallard egg from the North Roadside pond at Ouray NWR contained 63 ppm selenium and a grossly deformed embryo. Clearly, selenium was an issue at both Utah sites in 1988. None of the duck eggs from Utah sites contained 3 ppm mercury.

Benton Lake NWR in Montana had a large population of nesting ducks in 1989; 13.7% of the duck eggs contained 6 ppm selenium, and 2.2% of the duck eggs contained 10 ppm selenium. Selenium was highest in gadwalls (*Anas strepera*), which nest late—perhaps because they spend more time (exposure days) on the nesting grounds before laying eggs. We estimate that hatchability of a small percentage of duck eggs was adversely influenced by selenium in 1989. Eared grebe eggs (30%) also contained 6 ppm selenium, but none of the eggs contained 10 ppm selenium. The question of selenium effects on eared grebes depends on their sensitivity; i.e., do they respond like black-necked stilts or more like ducks? Boron was found at low concentrations, and mercury was not analyzed at Benton Lake.

Organochlorine (OC) pesticides were evaluated in selected species when OC pesticides were suspected of influencing productivity. Dichlorodiphenyl dichloroethylene (DDE) residues in white-faced ibis (*Plegadis chihi)* and snowy egret (*Egretta thula*) eggs showed no signs of decreasing, compared to earlier years in the Lahontan Valley when DDE adversely impacted reproductive success of both species. DDE residues declined in the black-crowned night-heron eggs from earlier years and was no longer a threat to reproductive success in the Lahontan Valley. Likewise, DDE declined in black-necked stilts and was not considered a threat in the Lahontan Valley. Eared grebes contained extremely low levels of DDE in their eggs in both the Lahontan Valley and western Wyoming. The other OCs were extremely low in all eggs.

Introduction

During the mid-1980s, concern increased about the quality of irrigation drainage water (i.e., the surface and subsurface water draining irrigated fields and its potential effects on fish and wildlife). Subsurface drainage water from irrigated land in the western part of the San Joaquin Valley of California contained high concentrations of selenium. In 1983, the U.S. Fish and Wildlife Service discovered dead waterbirds, embryo abnormalities, and reproductive failures in waterfowl and other waterbirds at Kesterson National Wildlife Refuge (NWR). These adverse effects were conclusively linked to irrigation drainage water entering Kesterson NWR from the western San Joaquin Valley (Ohlendorf et al., 1986a, 1986b; Presser and Ohlendorf, 1987). In response to these concerns, the Department of the Interior began the National Irrigation Water Quality Program (NIWQP) in 1985.

The NIWQP is an intradepartmental program that evaluates Department of the Interior (Bureau of Indian Affairs and Bureau of Reclamation [Reclamation]) irrigation projects. The program considers drainwater contamination and related impacts to endangered species or migratory birds, assesses legal responsibilities that are associated with environmental laws, develops alternatives for remediation, and implements alternatives. Program participants are the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the Bureau of Indian Affairs, and Reclamation. These agencies work cooperatively to resolve endangered species and migratory bird treaty issues on Reclamation and Bureau of Indian Affair's irrigation projects. The program is managed by Reclamation on behalf of the Department of the Interior.

As part of the NIWQP studies, nine locations were chosen for reconnaissance investigations in 1986, and other locations were chosen later. The reconnaissance investigations reported concentrations of organic and inorganic contaminants in water, bottom sediments, and biota in the wildlife areas and compared the analytical results to various numerical guidelines and background information (see Lambing et al., 1988; Peterson et al., 1988 ; Radtke et al., 1988 ; Wells et al., 1988; Low and Mullins, 1990; Setmire et al., 1990; Sorenson and Schwarzbach, 1991 ; Ong et al., 1991; and Dileanis et al., 1992). In addition to selenium, contaminants including arsenic, boron, and several other toxic metals and pesticides have been detected in numerous areas that receive irrigation drainage water in the Western United States.

In this report, we summarize our findings on contaminants in eggs, on hatchability, and on the occurrence of abnormalities. We also use information accumulated over the last decade to aid in interpreting residue concentrations in eggs. Selenium problems first documented at Kesterson NWR, California, were related to reproduction (e.g., low nest success and abnormalities) (Ohlendorf et al., 1986a, 1986b). During the period 1986-89, we collected eggs and determined hatchability or nesting success of waterbirds at five NWRs in five States and some adjacent areas. Reconnaissance investigations occurred at four of the five general locations we studied: (1) Stillwater Wildlife Management Area (WMA), Nevada (Hoffman et al., 1990); (2) Malheur NWR, Oregon (Rinella and Schuler, 1992); (3) Benton Lake NWR, Montana (Knapton et al., 1988); and (4) Ouray NWR, Utah, on the middle Green River (Stephens et al., 1988). Seedskadee NWR, on the upper Green River in Wyoming, was not designated for reconnaissance, although the Wind River (Ocean Lake, near Riverton, Wyoming) was designated for reconnaissance (Peterson et al., 1991) and for field screening (Grasso et al., 1995). At Stillwater WMA, Benton Lake NWR, and Ouray NWR, additional detailed studies were conducted (Hallock and Hallock, 1993; Hoffman, 1994; Lambing et al., 1994; Nimick et al., 1996; and Stephens et al., 1992). Egg residue data from Benton Lake and Freezeout Lake, collected during this study in 1989, were listed in Lambing et al. (1994), but with no interpretation. No other residue data from eggs reported here has been reported elsewhere, except that one egg with a high selenium concentration was collected from a mallard nest at Ouray NWR in 1988, from which an egg was also collected by Waddell (see section on Ouray NWR and Stewart Lake, Utah). Mercury and boron were evaluated at most study areas. Organochlorine (OC) insecticides and polychlorinated biphenyls (PCBs) were evaluated in eggs of selected species, especially black-crowned night-herons (*Nycticorax nycticorax*), snowy egrets (*Egretta thula)*, and white-faced ibis (*Plegadis chihi*), that showed DDE-related reproductive problems in earlier studies from the Intermountain West (Henny et al., 1984; Henny et al., 1985; and Henny and Herron, 1989). High concentrations of DDE would not be expected in lower food chain species like ducks and coots. This field study was not adequate to evaluate interactions of trace elements on reproductive success (i.e., selenium and mercury); therefore, risk was evaluated for individual elements, and at most locations, only a single trace element was of concern.

Study Areas

Nevada

The Lahontan Valley includes Stillwater WMA and is located in the Carson Desert hydrographic area of the lower Carson River Basin, in Churchill County, approximately 113 kilometers (km) east of Reno, Nevada (figures 1 and 2). The 90,653-hectare (ha) Stillwater WMA was established in 1948 under a cooperative agreement between the U.S. Fish and Wildlife Service, the Nevada Department of Wildlife, and the Truckee-Carson Irrigation District. Stillwater WMA obtains water through controlled releases from irrigation canals (Newland's Irrigation Project, initiated in 1902), from surface and subsurface irrigation drains (drainwater), and precautionary releases from the Lahontan Reservoir during wet years. Historically, the Carson River was the primary water source for Lahontan Valley. The river flowed unrestricted through a series of shallow lakes and marshes before discharging into the Carson Sink. Prior to regulation, the Carson River channel in Lahontan Valley meandered and frequently shifted course (Hoffman, 1994). For a schematic diagram of the present flow system of water in the Lahonton Valley, including the major canals and drains in the Newland's Irrigation Project, see figure 2.

The quantity of irrigation return flows and the percentage of the total flow that reaches the wildlife areas sampled are imprecisely known and may be highly variable from year to year, depending on annual water availability. All the locations sampled in the Lahonton Valley during this study were influenced by return flow drainwater, except Sheckler Reservoir and perhaps S-Line Reservoir (the latter may have been slightly influenced by return drainwater).

The Humboldt/Toulon site is located in the Humboldt WMA, north of the Carson Sink, which is at the terminus of the Humboldt River. Both Lahontan Valley and Humboldt/Toulon wetlands receive irrigation drainage from soils deposited on the bottom of ancient Lake Lahontan and contain similar naturally occurring elements. Thus, there is some logical basis for including Humbolt/

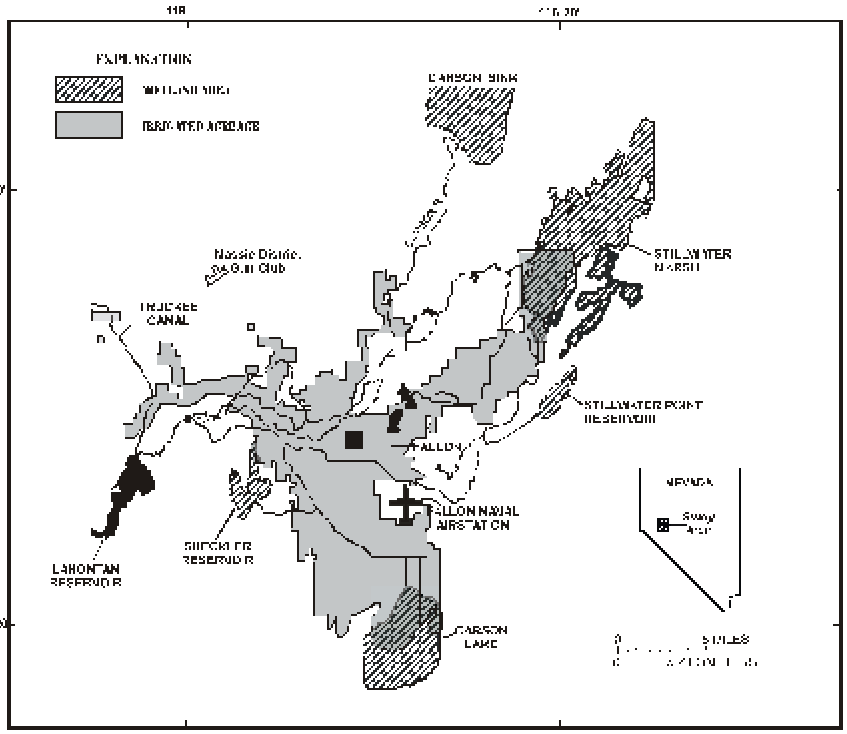


Figure 1.—Irrigated acreage in Fallon area of Newland’s Project, Nevada.

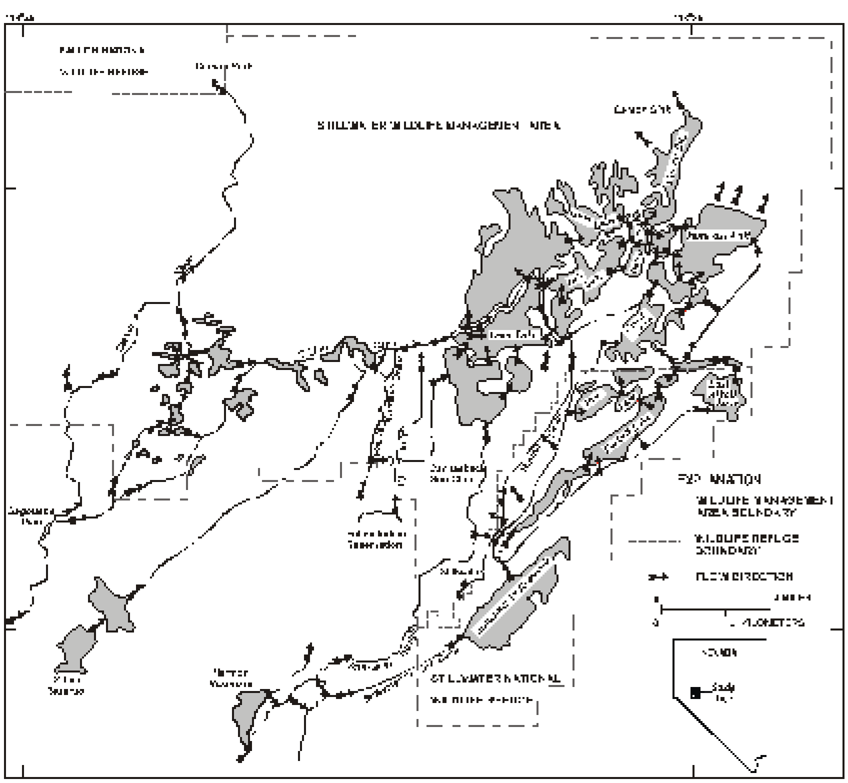


Figure 2.—Stillwater National Wildlife Refuge and Wildlife Management Area, Nevada.

Toulon as part of the Lahontan Valley. In addition, the Carson Sink was full of water at the beginning of this study, and both sites were joined by common water. Some individuals may oppose including Humboldt/Toulon in the Lahontan Valley. Data will be presented separately for each collection location, but data (including Humboldt/Toulon) were sometimes combined in summaries. Two points need to be made about the Humboldt/Toulon site: (1) mercury from the Carson River system probably seldom directly reached the location, and (2) drainwater pollutants originating from the Newland's Irrigation Project in the Lahontan Valley probably seldom directly reached the location. Sources of contamination in the Humboldt/Toulon wetlands were identified as its own irrigation drainwater, the hydrogeologic setting, and historical mining activities.

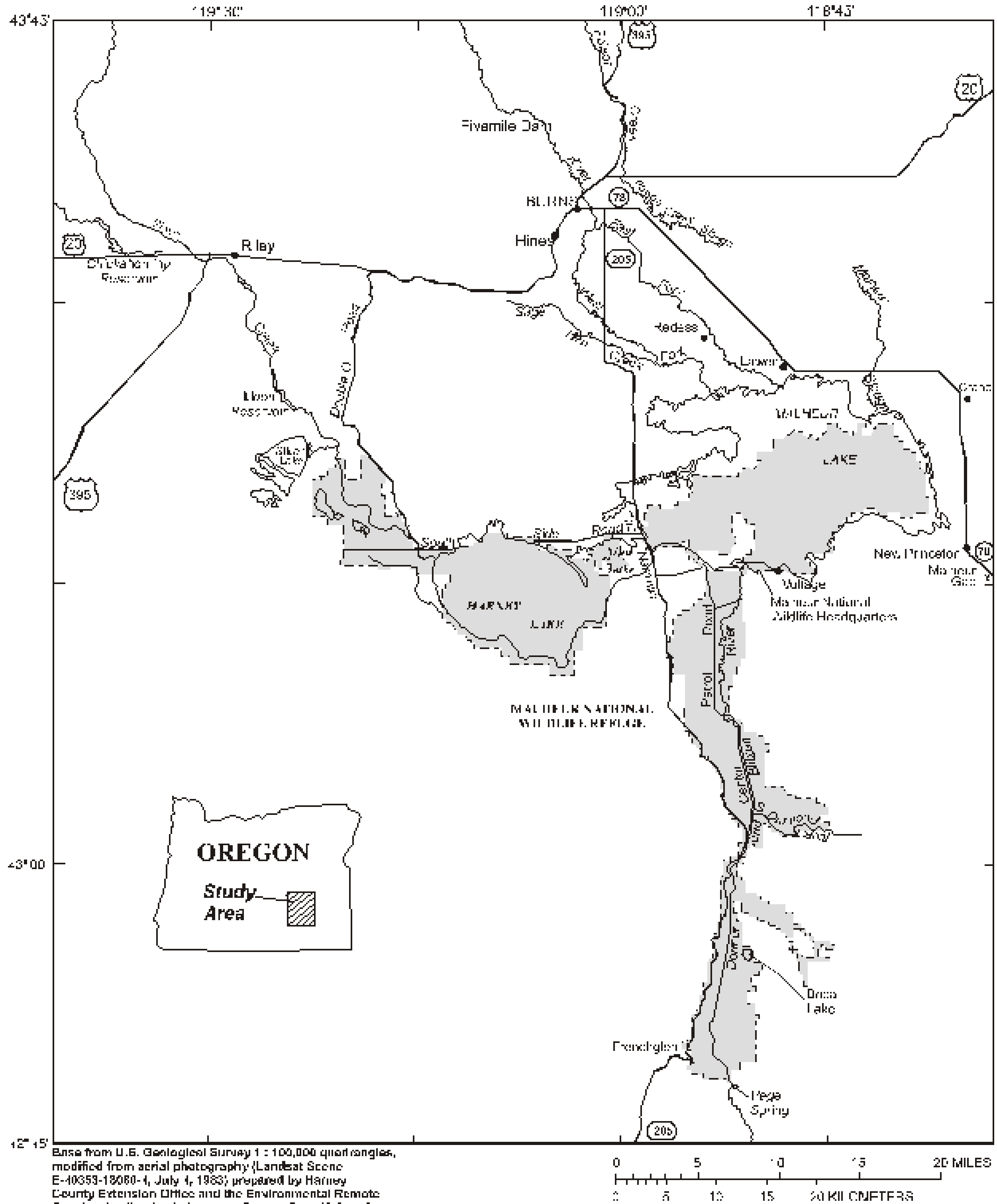
Because birds fly around before establishing nesting sites, residues found in eggs at any of the sites above (as well as others listed later) may be partially influenced by locations other than the immediate nest site. The potential for offsite influences on egg residues varies, depending on the species of bird, the size of a species typical foraging range, and the persistence of the contaminant in the bird. More sedentary species on the breeding grounds, such as grebes and shorebirds, usually lay eggs with residues reflecting more local contaminant conditions, whereas more wide-ranging species, such as most ducks, are probably less reliable indicators of contaminant conditions immediately adjacent to the nest (Skorupa and Ohlendorf, 1991).

Between 1859 and 1890, mercury amalgamation was used in processing gold and silver ore from the Comstock Mining District, approximately 110 km west of Stillwater WMA (Smith, 1943). As much as 7,500 tons of elemental mercury may have been lost during milling operations (Bailey and Phoenix, 1944). Most of the mercury was discarded in mill tailings or discharged into the Carson River in mill effluent. Elevated mercury concentrations persisted in water, sediment, and biota 100 years later (see review, Tuttle and Thodal, 1998). Henny and Herron (1989) reported that mercury may have adversely affected the number of young white-faced ibis produced per nesting attempt at Carson Lake in 1985-86. Carson Lake is located in one of the old beds of the Carson River. Therefore, mercury is of special concern in the Lahontan Valley, especially near old Carson River channels where water flowed during the Comstock mining days.

Oregon

Malheur NWR is part of a closed aquatic system located 37 km south of Burns, in Harney County, Oregon (figure 3). The 74,464 ha refuge receives surface water from four tributaries (Blitzen River, Donner River, Silvies River, and Silver Creek), draining 285,000 ha of surrounding land. Surface water has been used for irrigation in the Harney Basin since the early 1900s. In recent times, high capacity irrigation wells have been installed to expand farming practices within the basin.

Record snowfalls and unusually cool summers, beginning in 1982, caused Malheur Lake surface elevation to rise drastically. From 1984 to 1986, Malheur Lake reached a lake-surface elevation of 4,102.4 to 4,102.6 feet (ft), the highest levels recorded since 1903. Over 68,000 ha of land were inundated at this lake level (Hubbard, 1989). The extensive enlargement of the lake system caused the coalescing of Malheur, Mud, and Harney Lakes into one large lake. Below-normal snow precipitation patterns, beginning in 1987, caused the lake-surface elevation to recede slowly (maximum level of 4,101.1 ft in 1987, 4,099.1 ft



Base from U.S. Geological Survey 1 : 100,000 quadrangles, modified from aerial photography (Landsat Scene E-40353-18080-4, July 4, 1983) prepared by Harney County Extension Office and the Environmental Remote Sensing Application Laboratory Oregon State University (4/84).

Figure 3.—Malheur National Wildlife Refuge, Oregon.

in 1988, and 4,098.4 ft in 1989) (Rinella and Schuler, 1992).

Nesting studies at Malheur NWR were conducted during extremely high water years (1986 and 1987). The same water pattern existed for the Lahontan Valley during this study.

Eggs collected at the Malheur NWR were divided into two general categories: (1) those near Malheur Lake, including surrounding fields and ponds, and (2) those near Harney Lake, including surrounding fields and ponds. The Narrows Road separated the two localities.

Montana

Benton Lake NWR is a 4,724 ha refuge located in a closed basin in Cascade and Chouteau Counties, 24 km north of Great Falls, Montana (figure 4). The refuge contains about 1,300 ha of open water and dikes, 870 ha of lakeshore and emergent vegetation, and 2,554 ha of uplands. Benton Lake NWR ranks as one of the premier waterfowl producing refuges in the Nation, with annual duck production ranging from 8,000 to 40,000 ducks per year. The refuge currently receives about 8,000 acre-feet of water from Muddy Creek to supplement runoff from the 62,200 ha Lake Creek watershed. The supplemental water is pumped out of Muddy Creek, which collects irrigation drainwater from the Sun River Irrigation Project, into Benton Lake through Lake Creek. Saline seeps also contribute water to Benton Lake.

Benton Lake was divided into six units. Unit 1 is near the source of the water supply, and Unit 5/6 is the most distant. Locations of nests were recorded by unit and further separated into those near (within 20 meters) seeps and those away from seeps. Saline seeps were common on the side hills along the southwest side of Benton Lake. The uplands above the side hills were planted in cereal grain (primarily wheat) and were not irrigated.

Freezeout Lake Game Management Area (GMA) was established in 1952 and is managed by the Montana Department of Fish, Wildlife, and Parks. This 4,856 ha reserve, divided equally into wetlands and uplands, lies in Teton County, approximately 56 km west of Great Falls, Montana. Water for the reserve comes from spring runoff of surrounding areas, Reclamation's Sun River Irrigation Project, saline seeps of surrounding nonirrigated farmland, and irrigation drainage.

Wyoming

Seedskadee NWR is located in Sweetwater County, along the Green River, approximately 40 km northwest of Green River, Wyoming (figure 5). This 6,007 ha refuge in southwestern Wyoming was established in 1965 to provide waterfowl habitat as mitigation for loss of wildlife habitat resulting from the construction of Fontenelle and Flaming Gorge Reservoirs. Water for this refuge comes from spring runoff and water diverted from the Green River. The Big Sandy River flows into the Green River at the lower end of Seedskadee NWR.

Other study sites included lakes and ponds within the Riverton Reclamation Project Area, near Riverton, in central Wyoming, and the Willis Ranch (a proposed National Wildlife Refuge) along the Bear River, 10 km south of Cokeville, Wyoming, in the southwest corner of the State. Old Eden Reservoir is located near the Big Sandy River, about 60 km upstream from where the river flows into the Green River. Water from Eden Reservoir (above Old Eden Reservoir) is used to

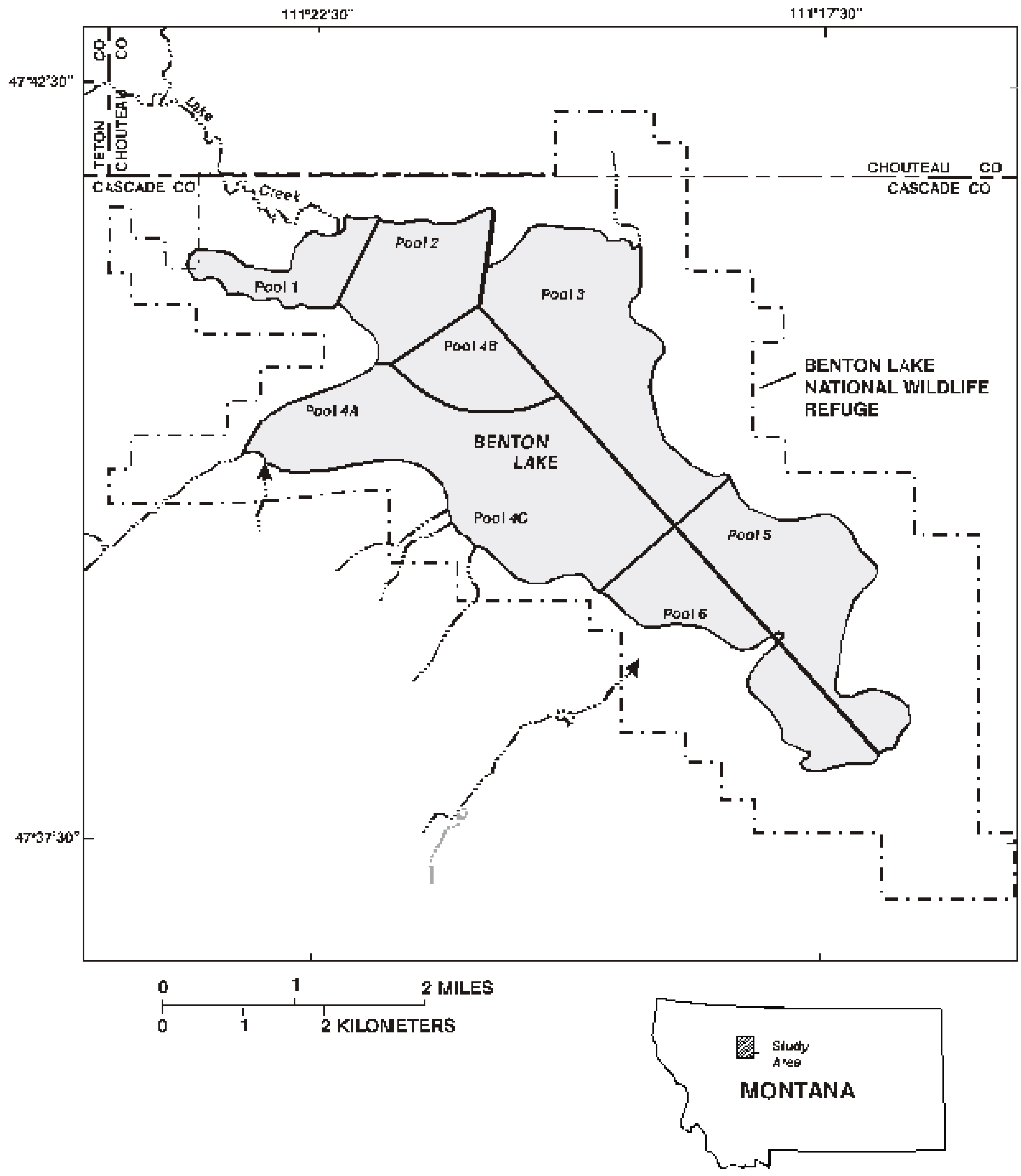


Figure 4.—Benton Lake National Wildlife Refuge, Montana.

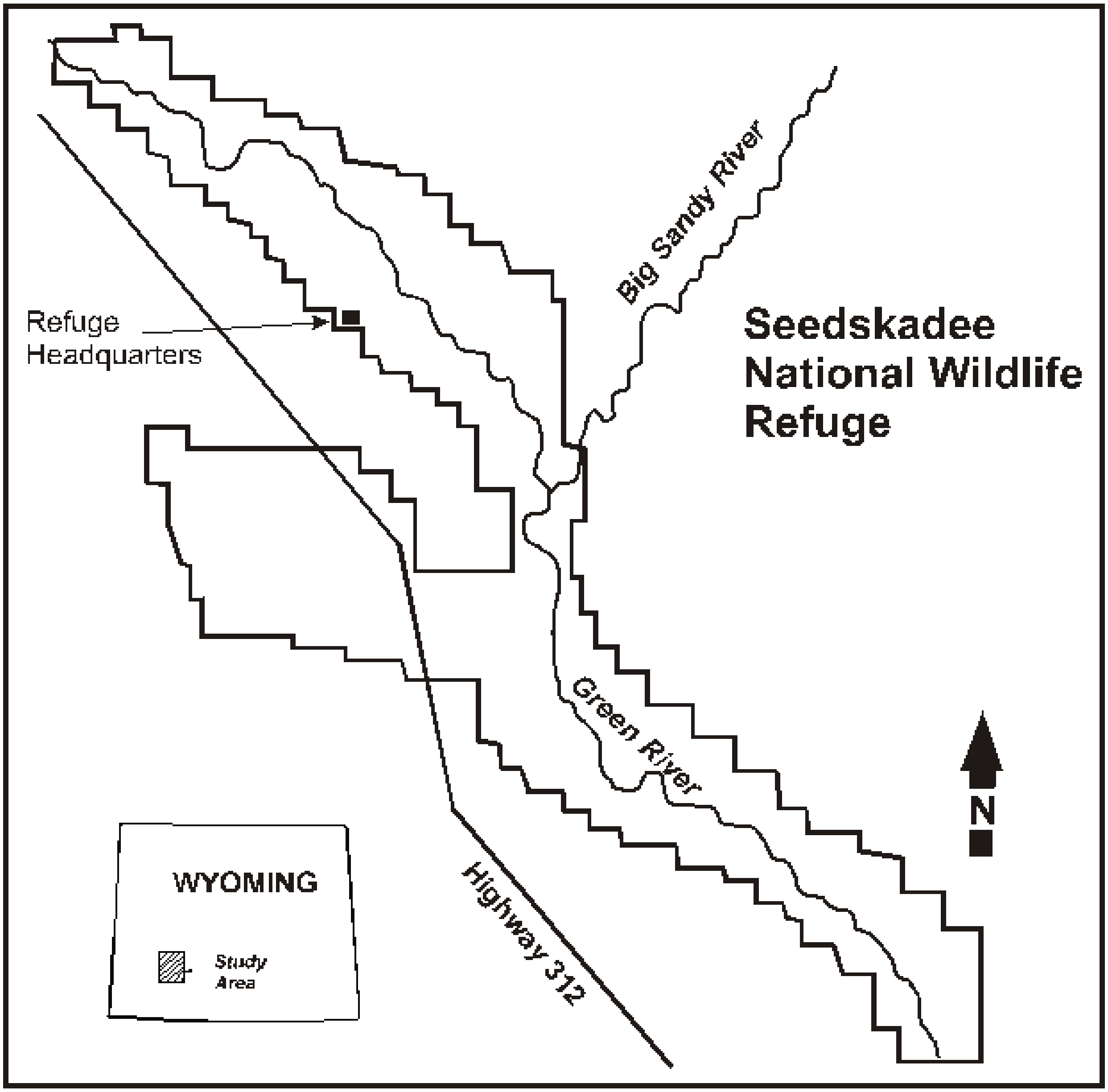


Figure 5.—Seedskadee National Wildlife Refuge, Wyoming.

irrigate agricultural crops in the Farson-Eden area. Waste water is returned to the Big Sandy River through agricultural drains and seeps. Water in the Big Sandy River below Farson-Eden is cloudy, almost milky in summer.

Utah

Ouray NWR is located in Uintah County, along the Green River, 48 km southwest of Vernal, Utah (figure 6). This 4,647 ha refuge was established in 1961, primarily for waterfowl habitat. Water is supplied to the refuge from the Green River, spring runoff, and irrigation drainage. Two ponds near the entrance road, which obtained their water from seeps adjacent to agricultural land, were of special concern.

Stewart Lake WMA lies adjacent to the Green River in Uintah County, approximately 19 km southeast of Vernal, Utah. At the time of the study, the primary source of water for this 101 ha reserve was spring runoff, the Green River during high water, and flows of four groundwater drains and a surface discharge channel from irrigated farmland.

Methods

Field Methods

During the 1986 nesting season, waterbird nests were marked, and one egg was collected from each nest for chemical analysis of trace elements. Marked nests were visited at 7- to 10-day intervals to determine their fate. The initial year of the study produced little useful information on hatching success in relation to contaminants from sample eggs at wild duck nests because a high percentage of nests at Malheur NWR and Stillwater WMA were destroyed by predators. Therefore, in later years, two eggs from each duck nest were placed in an incubator for artificial hatching, in addition to a third egg that was collected for residue analysis. We purchased two Petersime® Model No. 4 Incubators (Petersime Incubator Company, Gettysburg, Ohio). These incubators were used at Malheur NWR and Stillwater WMA in 1987, at Stillwater WMA and Seedskadee NWR in 1988, and at Benton Lake NWR in 1989. Duck eggs collected in the field for incubation were immediately placed in a Koolatron Caddy II (Koolatron Corporation, Batavia, New York) for transportation to the incubator. Transit time from the field to the incubator and Koolatron temperature (temperature held between 32 and 35 °C) were recorded for each sampled nest. Incubators were operated and maintained according to operating instructions. The incubation temperature was set at 37.5 °C dry bulb, using contact thermometers. A wet bulb temperature between 32-35 °C was kept to ensure proper humidity during incubation. Eggs were automatically turned at 2-hour intervals. Dry and wet bulb temperatures were recorded twice daily. A few eggs were eliminated from this analysis. Eliminated eggs included those that were cold when collected (unless fresh), eggs collected from dump nests, eggs overheated during incubator malfunction, and eggs from nests with incomplete information.

Predation was less important for other waterbirds than for ducks, and only one egg per nest was collected from other waterbirds for residue analysis; the remaining eggs were monitored in the nest. However, fluctuations in water levels (flooding or total loss of water) at various arid locations sometimes seriously affected nesting success of other waterbirds. We used the sample egg technique (see Blus, 1984) of collecting one egg from a clutch to represent egg residue concentrations from the clutch and leaving the remaining eggs in the nest to evaluate nesting success or abnormalities with respect to egg

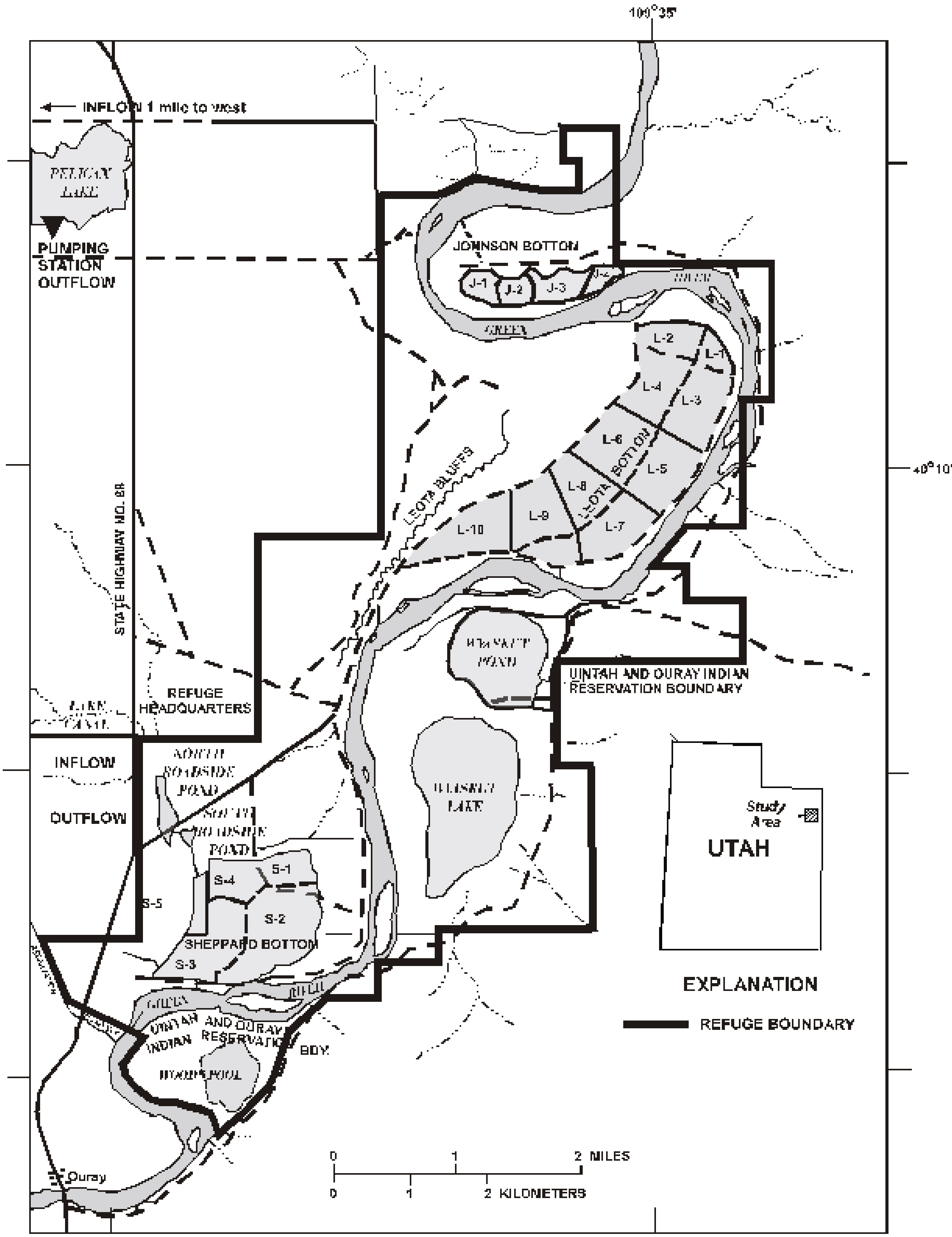


Figure 6.—Ouray National Wildlife Refuge, Utah.

residue concentrations from that nest. Generally, egg residue concentrations are quite consistent among eggs within a clutch. This consistency permits the sample egg technique to be effective (Blus, 1984).

The same species were chosen at each refuge, if available, so that residue concentrations among refuges could be compared. Eggs from gadwall (*Anas strepera*), mallard (*Anas platyrhynchos*), American coot (*Fulica americana*), black-necked stilt (*Himantopus mexicanus*), eared grebe (*Podiceps nigricollis*), and northern harrier (*Circus cyanus*), which is perhaps the most representative bird of prey of the wetlands, were collected at most refuges. Most of the same species were previously studied in California.

Laboratory Methods

Fertility, viability, stage of development, and observations of embryonic abnormalities were recorded when unhatched eggs or eggs randomly collected for residue analyses were opened. Embryos having observable abnormalities were sent to Patuxent Wildlife Research Center (PWRC), Laurel, Maryland, for detailed examination. Egg contents for residue analyses were stored frozen in chemically cleaned glass jars with teflon-lined lids and then shipped to PWRC for chemical analyses. Analytical chemistry was then conducted either at PWRC or at contract laboratories authorized through the Patuxent Analytical Control Facility (PACF). Contract laboratories used for inorganic chemistry were the Environmental Trace Substances Research Center (ETSRC), University of Missouri, Columbia, Missouri; Hazelton Laboratories America, Inc. (HLA), Madison, Wisconsin; and Research Triangle Institute (RTI), Research Triangle Park, North Carolina. Mississippi State Chemical Laboratory (MSCL), Mississippi State University, Mississippi State, Mississippi, was the contract laboratory used for organic chemistry.

All egg samples were homogenized with a virtis blender. Percent moisture was determined by placing preweighed aliquot of egg homogenates into a drying oven set at ~105 °C until dry. Egg samples were then reweighed to determine percent moisture. Egg samples submitted for inorganic chemistry were analyzed for boron, mercury, and selenium using analytical procedures validated by PACF. In general, a 0.5-gram aliquot of each egg sample was digested using nitric acid. Perchloric acid was also used in digesting samples by ETSRC. Digested samples were brought to a final volume of 50 milliliters (mL). Selenium concentrations were determined using either stabilized temperature platform graphite furnace atomic absorption or hydride generation atomic absorption. Boron concentrations were determined using either an inductively coupled plasma (ICP) spectrophotometer or a Gilford response UV-VIS spectrometer. Total mercury concentrations were determined by cold vapor atomic absorption.

Wet weight detection limits for total mercury were: from PWRC (for Malheur NWR 1986, 1987; Lahontan Valley 1986, 1987) 0.02 ppm; from ETSRC (for Lahontan Valley, 1988) 0.02 ppm; from ETSRC (for Wyoming and Utah, 1988) 0.005 ppm; and (for Montana, 1989) not analyzed. Wet weight detection limits for selenium were: from PWRC (for Malheur NWR, 1986, 1987; Lahontan Valley, 1986, 1987) 0.10 ppm; from ETSRC (for Lahontan Valley 1988) 0.20 ppm; from ETSRC (for Wyoming and Utah, 1988) 0.10 ppm; from HLA (for Montana, 1989) 0.10 ppm. Wet weight detection limits for boron were: from PWRC (for Malheur NWR, 1987; Lahontan Valley, 1987, 1988) 0.50 ppm; from ETSRC (for Malheur NWR, 1986)

0.50 ppm. Dry weight detection limits for boron were: from ETSRC (for Wyoming and Utah, 1988) 2.0 ppm; from HLA (for Montana, 1989) 1.5 ppm. Wet weight (ww) concentrations were converted to dry weight (dw) using percent moisture in the egg. Wet weight detection limits were also converted to dry weight. All trace element residue data presented in this paper are dry weight, unless otherwise noted.

Egg samples submitted for organic chemistry were analyzed by MSCL. A 10-gram aliquot of each egg sample was thoroughly mixed with anhydrous sodium sulfate and extracted with hexane. The extract of each sample was concentrated and transferred to a glass chromatographic column containing 20 grams of florisil. The column was eluted with 200 mL of 6% diethyl ether/ 94% petroleum ether (fraction 1), followed by 200 mL 15% diethyl ether/85% petroleum ether (fraction 2). Fraction 2 was concentrated to an appropriate volume for quantification of residues, using a gas chromatograph equipped with an electron capture detector. Fraction 1 was concentrated and transferred to a silicic acid chromatographic column for further separation of PCBs and other organochlorines. Three fractions were eluted from the silicic acid column and concentrated to the appropriate volume for quantification of residues, using a gas chromatograph equipped with an electron capture detector. Fraction 2 of the florisil extraction contained residues of dieldrin, endrin, and dacthal. Fraction 1 of the silicic extractions contained residues of hexachlorobenzene (HCB) and mirex, with fraction 2 containing PCBs and p,p'-DDE, and fraction 3 containing -BHC, -BHC, -BHC, -BHC, oxychlordane, heptachlor epoxide, -chlordane, -chlordane, *trans*-nonachlor, toxaphene, o,p'-DDE, p,p'-DDT, *cis*-nonachlor, o,p'-DDT, p,p'-DDD, p,p'-DDT, mirex, and dicofol. The level of detection for organochlorine pesticides and their metabolites was 0.01 ppm ww, except for toxaphene, which was 0.05 ppm ww. PCBs had the same detection limit as toxaphene. Egg contents were converted to their approximate fresh wet weight using egg volume (Stickel et al., 1973); all organochlorine residues are reported on a fresh wet weight basis.

Laboratory quality control was evaluated by PACF. The precision and accuracy of analyses were confirmed using procedural blanks, duplicate samples, spiked samples, and reference standards. All contaminant analyses received a quality assurance review at PACF.

Statistical Methods

Not all nests could be located on the day the first egg was laid. Eggs in nests located later in the nesting cycle would probably be more successful because of fewer days exposed to threats, including predation. Thus, unadjusted nesting success data (apparent nesting success), when it includes nests initially located at various stages of egg laying or incubation, would be biased high. An approach was needed that would incorporate as much nesting information as possible, while providing an unbiased estimate of nesting success. Ornithologists now use the Mayfield Exposure Day Method to fully use information from nests initially located at various stages of the nesting cycle (Mayfield, 1975; Bart and Robson, 1982; and Sauer and Williams, 1989). The approach calculates daily survival rates for nests, and overall success can be estimated by assigning various species or groups of species the number of exposure days needed for their eggs to be laid and to hatch (species with precocial young). In the case of some locations (refuges or portions thereof), a Mayfield estimate was not computed because an inadequate number of nests were studied (<10) .

To determine the number of exposure days for the model, mean values for clutch size, incubation term (days), and age of clutches at hatching (days) were taken from Klett et al., (1986) for ducks and Harrison (1978) for American coots, northern harriers, and black-necked stilts. Based upon the species composition of the nests in our duck nest samples, we used 34.5 exposure days for dabbling ducks, 35 days for diving ducks, and 30 days for American coots to estimate nesting success.

The Mayfield Exposure Day Method can be an insensitive endpoint because it is usually used only to classify the percentage of successful nests (i.e., those in which at least one young hatched and departed the nest). The insensitive aspect results from the fact that contaminants do not always cause all eggs in a clutch to fail until the contaminant concentration is exceptionally high—only a portion of the eggs generally fail to hatch at lower effect concentrations, and the nest would still be classified successful by the Mayfield approach. However, with the Mayfield approach for ducks, the number of eggs that hatched in each nest was accounted for, and the number of young ducklings produced per nesting attempt was determined (percentage of successful nests X number of young hatched in each successful nest). However, similar determinations could not be made for all waterbirds, especially those with precocial young with only pipchips (small eggshell fragments from chick pipping) remaining in the nest.

Residue concentrations were log-transformed for statistical analyses. When >50% of the eggs contained detectable concentrations, values below the detection limit were assigned a value of one-half the dry weight detection limit for statistical calculations. Because of unequal sample sizes, the General Linear Models Procedure (SAS Institute, 1985) for one-way or two-way analysis of variance (ANOVA) was used when comparing residue concentrations. Tukey's Studentized Range Test was used to separate means. When no significant differences in residue concentrations among locations within a year for a species or a group of ducks was found, locations were combined. For eggs placed in incubators, those that hatched and those that failed to hatch were evaluated by chi-square tests. Unless otherwise noted, statistical significance was P 0.05.

Results

Trace Elements in Eggs

Lahontan Valley, Nevada.—Selenium concentrations in waterbird eggs collected from nine areas studied in the Lahontan Valley in 1986, 1987, and 1988 are shown in table 1. When dabbling duck data were available for all three years at Carson Lake and Lead Lake, significantly lower selenium concentrations were reported in 1986 than in 1987 or 1988. American coots and black-necked stilts at the same two lakes showed a similar general pattern, with selenium concentrations significantly higher in 1988.

Those species or groups showing significant differences in selenium concentrations among locations included dabbling ducks (1987 and 1988), American coot (1986), eared grebe (1986), and black-necked stilt (1986, 1987, and 1988) (table1). As might be expected, these species or groups included many with the largest sample sizes. For dabbling ducks in 1987, the mean selenium concentration at Humboldt/Toulon (4.48 ppm) was significantly higher than at any other location (range 1.06 to 1.44 ppm). Furthermore, selenium concentrations were consistently higher in all dabbling duck species sampled at Humboldt/Toulon in 1987. In 1988, no sampling occurred at Humboldt/Toulon, but S-Line Reservoir dabbling ducks (1.89 ppm) contained significantly higher selenium concentrations than those at Carson Lake

Table 1.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Carson Lake								
Dabbling ducks	11	**0.72B**	23	**1.06 A**	13	**1.22 A**		
Mallard			7	1.10	3	0.82	10	1.01
Gadwall	7	0.70	2	0.91			9	0.74
Cinnamon teal	4	0.76	14	**1.07 A**	10	**1.37 A**	28	1.11
Diving ducks	26	**0.63 B**	21	**1.05 A**	10	**1.38 A**		
Redhead	19	**0.60 B**	14	**1.01 AB**	6	**1.30 A**		
Ruddy duck	7	**0.74 B**	7	**1.13 A**	4	1.53		
American coot	15	**0.60 B**	15	**0.60 B**	6	**1.34 A**		
Eared grebe	11	2.36					11	2.36
Black-necked stilt	24	**0.80 C**	10	**1.05 B**	7	**1.70 A**		
Great blue heron					13	2.58	13	2.58
Sheckler Reservoir								
Dabbling ducks			10	1.30	1	1.10	11	1.28
Mallard			5	1.36	1	1.10	6	1.32
Cinnamon teal			5	1.24			5	1.24
Diving ducks			2	0.73			2	0.73
Redhead			1	0.64			1	0.64
Ruddy duck			1	0.83			1	0.83
American coot			7	0.43			7	0.43
Humboldt/Toulon[1]								
Dabbling ducks			5	4.48			5	4.48
Mallard			1	3.73			1	3.73
Gadwall			1	5.11			1	5.11
Cinnamon teal			3	4.56			3	4.56
Diving ducks			2	5.42			2	5.42
Redhead			1	5.37			1	5.37
Ruddy duck			1	5.47			1	5.47
American coot			4	2.33			4	2.33
Black-necked stilt			12	3.65			12	3.65
S-Line Reservoir								
Dabbling ducks			8	**1.18 A**	6	**1.89 A**	14	1.44
Mallard			7	**1.18 A**	6	**1.89 A**	13	1.47
Cinnamon teal			1	1.22			1	1.22

Table 1.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88 (continued)

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Redhead			1	1.90			1	1.90
Canada goose					2	0.76	2	0.76
American coot			2	0.64			2	0.64
Great blue heron					4	3.09	4	3.09
Lead Lake								
Dabbling ducks	8	**0.80 B**	9	**1.44 A**	30	**1.37 A**		
Mallard			2	1.18	8	1.49	10	1.42
Gadwall	7	**0.81 B**	6	**1.56 A**	11	**1.47 A**		
Cinnamon teal	1	0.74	1	1.29	11	1.21	13	1.17
Diving ducks	1	1.03	2	1.07	2	1.42	5	1.19
Redhead	1	1.03	2	1.07	1	1.30	4	1.11
Ruddy duck					1	1.55	1	1.55
Canada goose					4	0.78	4	0.78
American coot	9	**0.93 C**	8	**0.64 B**	22	**1.24 A**		
Eared grebe			4	3.82	30	3.73	34	3.74
Black-necked stilt	4	1.61	11	**1.16 B**	19	**2.04 A**		
Foxtail Lake								
Cinnamon teal			2	0.96			2	0.96
Diving ducks			6	1.26			6	1.26
Redhead			4	1.41			4	1.41
Ruddy duck			2	1.02			2	1.02
American coot	1	0.80	6	0.75			7	0.75
Eared grebe	10	3.45					10	3.45
Stillwater Point Reservoir								
Redhead			1	2.98			1	2.98
American coot	5	1.02	1	0.77			6	0.98
Eared grebe			3	4.57			3	4.57
Tule Lake								
Dabbling ducks	1	1.37	23	**1.19 B**	11	**1.79 A**		
Mallard			3	1.35	1	4.30	4	1.80
Gadwall			11	**1.30 B**	10	**1.64 A**		
Cinnamon teal			4	1.03			4	1.03
Northern pintail	1	1.37	5	0.99			6	1.04
American coot					2	1.45	2	1.45
Eared grebe			9	4.66			9	4.66

Table 1.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88 (concluded)

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Black-necked stilt	6	**1.29 B**	11	**1.21 B**	14	**2.36 A**		
Snowy egret					20	3.11	20	3.11
Massie/Desert Gun Club								
Redhead					2	2.12	2	2.12
Canada goose					1	1.86	1	1.86
Great blue heron					3	5.38	3	5.38
Areas Combined[2]								
Dabbling ducks	20	0.77					20	0.77
Mallard			25	**1.27 A**	19	**1.52 A**	44	1.37
Gadwall	14	**0.75 B**	20	**1.44 A**	21	**1.55 A**		
Cinnamon teal	5	**0.75 B**	30	**1.27 A**	21	**1.28 A**		
Northern pintail	1	1.37	5	0.99			6	1.04
Diving ducks	27	**0.65 B**	35	**1.22 A**	14	**1.48 A**		
Redhead	20	**0.62 B**	24	**1.36 A**	9	**1.45A**		
Ruddy duck	7	**0.74 B**	11	**1.25 AB**	5	**1.53 A**		
Canada goose					7	0.88	7	0.88
American coot			43	**0.68 B**	30	**1.27 A**		
Eared grebe			16	**4.42 A**	30	**3.73 B**		
Great blue heron					20	2.99	20	2.99
Snowy egret					20	3.11	20	3.11
Northern harrier[3]			2	2.57	1	3.90	3	2.95
American kestrel[3,4]			1	2.08			1	2.08

Note: Statistical tests conducted (BOLD) among years when sample size five eggs (one egg per nest). Means within each row sharing a letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species In each group were sometimes combined (see below).

[1] Adjacent to Lahontan Valley, but generally not recognized as part of it.

[2] If no significant difference among locations within a year, the data for a species, or group of species, were combined for that year.

[3] Exact locations not directly related to sites for waterbirds.

[4] Falco sparverius.

(1.22 ppm). All locations sampled in 1988 contained mean selenium residue concentrations within a relatively small range (1.22 to 1.89 ppm). The American coot, in 1986, contained selenium concentrations that were significantly higher at Stillwater Point Reservoir (1.02 ppm) than at Carson Lake (0.60 ppm). The eared grebe, in 1986, showed the same general pattern for selenium with eggs at Foxtail Lake (another site on Stillwater WMA), having significantly higher selenium concentrations (3.45 ppm) than at Carson Lake (2.36 ppm). Black-necked stilts at Tule Lake, in 1986 (also in Stillwater WMA), contained significantly higher concentrations of selenium (1.29 ppm) than at Carson Lake (0.80 ppm); 1987 concentrations were significantly higher at Humboldt/Toulon (3.65 ppm) than at Lead Lake (1.16 ppm), Tule Lake (1.21 ppm), and Carson Lake (1.05 ppm). Selenium in black-necked stilt eggs in 1988 was significantly higher at Tule Lake (2.36 ppm) than in earlier years (1.21 to 1.29 ppm) and was significantly higher than at Carson Lake (1.70 ppm) in 1988. Eared grebe eggs were collected at five of the above locations, and the grebes always had the highest selenium concentrations at each site. As a general pattern, selenium concentrations were highest at Humboldt/Toulon (most northern location, near Carson Sink), lowest at Carson Lake (most southern location), and intermediate at the Stillwater WMA sites. In addition, selenium concentrations were often significantly lower for many species in 1986 than in 1987 or 1988.

Mercury was usually analyzed in the same eggs that were evaluated for selenium in the Lahontan Valley. When duck egg data were available for all three years at Carson Lake and Lead Lake, mean mercury concentrations were often significantly higher in 1988, especially when compared to data from 1987 (table 2). American coots and black-necked stilts at Carson Lake and Lead Lake showed the same general pattern. As with selenium, if there were no significant differences in residue concentrations among locations within a year for a species or group of ducks, the areas were combined. However, several significant differences in mercury concentrations among locations were noted. In 1986, eggs of dabbling ducks at Carson Lake (0.98 ppm) contained significantly higher concentrations of mercury than at Lead Lake (0.49 ppm). Likewise, dabbling ducks at Carson Lake (0.66 ppm) and Sheckler Reservoir (0.63 ppm), in 1987, contained significantly higher mercury concentrations than at Humboldt/Toulon (0.16 ppm) or Tule Lake (0.18 ppm). The other locations were intermediate and not significantly different (S-Line Reservoir, 0.34; Lead Lake, 0.28 ppm). Similarly, in 1988, dabbling duck eggs at Carson Lake (2.04 ppm) and Lead Lake (2.24 ppm) contained significantly higher mercury concentrations than at S-Line Reservoir (0.92 ppm). At Tule Lake, mercury concentrations were intermediate and not significantly different (1.53 ppm). Also, American coots at Carson Lake (1.43 ppm) and Stillwater Point Reservoir (1.50 ppm), in 1986, contained significantly higher concentrations than at Lead Lake (0.74 ppm). American coots, in 1987, showed a pattern similar to Carson Lake (0.87 ppm) and Lead Lake (0.88 ppm), having significantly higher mercury concentrations than Sheckler Reservoir (0.32 ppm). Foxtail Lake (0.61 ppm) was intermediate and not significantly different. Black-necked stilt eggs, in 1987, contained significantly higher mercury concentrations at Carson Lake (0.87 ppm) and Lead Lake (0.86 ppm) than at Humboldt/Toulon (0.25 ppm) or Tule Lake (0.19 ppm). Again, in 1988, black-necked stilt eggs from Carson Lake contained the highest mercury concentrations (3.65 ppm), which were significantly higher than at Lead Lake (1.51 ppm) or Tule Lake (1.44 ppm).

Table 2.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Carson Lake								
Dabbling ducks	11	**0.98 B**	23	**0.66 B**	13	**2.04 A**		
Mallard			7	0.37	3	1.41	10	0.55
Gadwall	7	0.72	2	0.28			9	0.59
Cinnamon teal	4	1.67	14	**1.01 B**	10	**2.27 A**		
Diving ducks	26	**0.76 A**	21	**0.14 B**	10	**0.45 A**		
Redhead	19	**0.90 A**	14	**0.08 B**	6	**0.46 A**		
Ruddy duck	7	**0.48 A**	7	**0.42 A**	4	0.40	18	0.45
American coot	15	**1.43 AB**	15	**0.87 B**	6	**1.78 A**		
Eared grebe	11	1.05					11	1.05
Black-necked stilt	24	**2.54 A**	10	**0.87 B**	7	**3.65 A**		
Great blue heron					13	2.34	13	2.34
Sheckler Reservoir								
Dabbling ducks			10	0.63	1	0.44	11	0.61
Mallard			5	0.30	1	0.44	6	0.32
Cinnamon teal			5	1.32			5	1.32
Diving ducks			2	0.60			2	0.60
Redhead			1	0.64			1	0.64
Ruddy duck			1	0.56			1	0.56
American coot			7	0.32			7	0.32
Humboldt/Toulon[1]								
Dabbling ducks			5	0.16			5	0.16
Mallard			1	0.01			1	0.01
Gadwall			1	0.28			1	0.28
Cinnamon teal			3	0.30			3	0.30
Diving ducks			2	0.03			2	0.03
Redhead			1	0.01			1	0.01
Ruddy duck			1	0.08			1	0.08
American coot			4	0.19			4	0.19
Black-necked stilt			12	0.25			12	0.25
S-Line Reservoir								
Dabbling ducks			8	**0.34 A**	6	**0.92 A**	14	0.52
Mallard			7	**0.27 A**	6	**0.92 A**	13	0.47
Cinnamon teal			1	1.65			1	1.65

Table 2.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88 (continued)

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Redhead			1	0.21			1	0.21
Canada goose					2	0.22	2	0.22
American coot			2	0.76			2	0.76
Great blue heron					4	5.03	4	5.03
Lead Lake								
Dabbling ducks	8	**0.49 B**	9	**0.28 B**	30	**2.24 A**		
Mallard			2	0.05	8	2.82	10	1.28
Gadwall	7	**0.45 B**	6	**0.41 B**	11	**2.09 A**		
Cinnamon teal	1	0.82	1	0.93	11	2.02	13	1.78
Diving ducks	1	0.21	2	0.01	2	1.03	5	0.13
Redhead	1	0.21	2	0.01	1	1.10	4	0.08
Ruddy duck					1	0.96	1	0.96
Canada goose					4	0.18	4	0.18
American coot	9	**0.74 B**	8	**0.88 B**	22	**1.67 A**		
Eared grebe			4	1.29	30	1.27	34	1.27
Black-necked stilt	4	3.46	11	**0.86 B**	16	**1.51 A**		
Foxtail Lake								
Cinnamon teal			2	0.74			2	0.74
Diving ducks			6	0.16			6	0.16
Redhead			4	0.15			4	0.15
Ruddy duck			2	0.20			2	0.20
American coot	1	1.08	6	0.61			7	0.67
Eared grebe	10	1.10					10	1.10
Stillwater Point Reservoir								
Redhead			1	0.90			1	0.90
American coot	5	1.50	1	0.51			6	1.25
Eared grebe			3	2.02			3	2.02
Tule Lake								
Dabbling ducks	1	0.09	23	**0.18 B**	11	**1.53 A**		
Mallard			3	0.19	1	2.53	4	0.36
Gadwall			11	**0.11 B**	10	**1.45 A**		
Cinnamon teal			4	0.61			4	0.61
Northern pintail	1	0.09	5	0.22			6	0.19
American coot					2	1.67	2	1.67
Eared grebe			9	0.96			9	0.96

Table 2.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1986-88 (concluded)

Location	1986		1987		1988		Combined	
	n	Mean	n	Mean	n	Mean	n	Mean
Black-necked stilt	6	**2.34 A**	11	**0.19 B**	14	**1.44 A**		
Snowy egret					19	1.83	19	1.83
Massie/Desert Gun Club								
Redhead					2	0.09	2	0.09
Canada goose					1	0.29	1	0.29
Great blue heron					3	1.43	3	1.43
Areas Combined [2]								
Mallard			25	0.22			25	0.22
Gadwall	14	**0.57 B**	20	**0.19 C**	21	**1.76 A**		
Cinnamon teal	5	**1.45 AB**	30	**0.87 B**	21	**2.14 A**		
Northern pintail	1	0.09	5	0.22			6	0.19
Diving ducks	27	**0.72 A**	35	**0.14 B**	14	**0.41 A**		
Redhead	20	**0.84 A**	24	**0.09 B**	9	**0.35 A**		
Ruddy duck	7	**0.48 A**	11	**0.32 A**	5	**0.53 A**	23	0.40
Canada goose					7	0.20	7	0.20
American coot					30	1.69	30	1.69
Eared grebe	21	**1.07 A**	16	**1.19 A**	30	**1.27 A**	67	1.19
Black-necked stilt	34	2.59					34	2.59
Great blue Heron					20	2.53	20	2.53
Snowy egret					19	1.83	19	1.83
Northern harrier[3]			2	0.50	1	0.60	3	0.53
American kestrel[3]			1	0.17			1	0.17

Note: Statistical tests conducted (**BOLD**) among years when sample size five eggs (one egg per nest). Means within each row sharing a letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] Adjacent to Lahontan Valley, but generally not recognized as part of it.

[2] If no significant difference among locations within a year, the data for a species, or a group of species, were combined for that year.

[3] Exact locations not directly related to sites for waterbirds.

Mean mercury concentrations in the various species ranged from 0.08 to 3.65 ppm (minimum of 5 eggs). The highest mean was reported from black-necked stilts at Carson Lake in 1988.

Carson Lake generally had higher mean concentrations of mercury than sites at Stillwater WMA and the Humboldt/Toulon area, farther north. A review of mercury in detritus samples from the Lahontan Valley shows a similar pattern (see Hallock and Hallock 1993, figure 15). Mercury concentrations are generally higher in the Carson Lake area than farther north. Most likely, mercury from Comstock Mining was distributed primarily by flood events prior to the construction of Lahontan Dam in 1915, and the historic "normal path" of the Carson River was to Carson Lake, then to Stillwater WMA. For a historical review of the waterflow in the Carson River and the size of the wetlands, see Hallock and Hallock (1993). The mercury findings contrast with the selenium findings, where selenium levels in the eggs from Carson Lake were often among the lowest.

Boron was analyzed in waterbird eggs from the Lahontan Valley only in 1987, except for seven Canada goose (*Branta canadensis)* eggs collected in 1988 (table 3). Again, if no significant differences were found among locations, the areas were combined. Mean boron concentrations (n 5 eggs) were in the range of 1-8 ppm, with none of the duck eggs showing mean concentrations above mallards (4.20 ppm) and redheads (*Aythya americana*) (4.06 ppm) at Carson Lake. Mallard eggs contained significantly higher concentrations of boron at Carson Lake than at Sheckler Reservoir (1.07 ppm). At S-Line Reservoir, boron concentrations were intermediate (2.63 ppm) and not significantly different. Cinnamon teal (*Anas cyanoptera*) showed the same pattern, with Carson Lake (2.44 ppm) significantly higher than Sheckler Reservoir (1.04 ppm). American coot eggs contained the highest boron concentrations among the species studied, with significantly higher concentrations at Lead Lake (8.36 ppm), Foxtail Lake (6.41 ppm), and Carson Lake (5.93 ppm) than at Sheckler Reservoir (2.67 ppm). Black-necked stilt eggs showed consistent concentrations among all locations in 1987 (Carson Lake, 2.83 ppm; Lead Lake, 2.87 ppm; Humboldt/Toulon, 2.90 ppm; and Tule Lake, 3.68 ppm).

Malheur NWR, Oregon.—The refuge was divided into two general locations: Harney Lake and vicinity and Malheur Lake and vicinity. Waterbird eggs were collected in 1986 and 1987 at both locations (table 4). When adequate numbers of eggs were collected in both years for comparison at Harney Lake, selenium concentrations in dabbling ducks (0.58 vs. 0.89 ppm) and black-necked stilts (0.97 vs. 1.90 ppm) were significantly higher in 1987. By contrast, selenium concentrations in northern harrier eggs at Malheur Lake (2.06 vs. 1.25 ppm) were significantly higher in 1986. All other comparisons at Harney Lake between 1986 and 1987 and Malheur Lake between 1986 and 1987 were not significantly different. Only dabbling ducks showed significant differences in selenium concentrations between locations. Differences occurred in both 1986 and 1987. In both years, selenium concentrations were significantly higher at Malheur Lake than at Harney Lake (1.04 vs. 0.58 ppm in 1986 and 1.36 vs. 0.89 ppm in 1987). The selenium patterns for each species (except dabbling ducks) between 1986 and 1987 at Malheur NWR are best represented by the areas combined. Eight statistical comparisons for 1986 vs. 1987 were made for Malheur NWR (Malheur Lake and Harney Lake combined), and only three comparisons were significant (table 4). Gadwall and black-necked stilt eggs showed significantly higher selenium concentrations in 1987 than in 1986, but the northern harriers showed

Table 3.—Geometric mean boron concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1987-88

	1987	
Location	n	Mean
Carson Lake		
Dabbling ducks	23	3.14
Mallard	7	4.20
Gadwall	2	6.71
Cinnamon teal	14	2.44
Diving ducks	21	2.66
Redhead	14	4.06
Ruddy ducks	7	1.14
American coot	15	5.93
Black-necked stilt	10	2.83
Sheckler Reservoir		
Dabbling ducks	10	1.06
Mallard	5	1.07
Cinnamon teal	5	1.04
Diving ducks	2	0.27
Redhead	1	0.12
Ruddy duck	1	0.59
American coot	7	2.67
Humboldt/Toulon[1]		
Dabbling ducks	5	1.41
Mallard	1	5.80
Gadwall	1	0.40
Cinnamon teal	3	1.33
Diving ducks	2	1.62
Redhead	1	2.20
Ruddy duck	1	1.20
American coot	4	5.52
Black-necked stilt	12	2.90
S-Line Reservoir		
Dabbling ducks	8	2.29
Mallard	7	2.63
Cinnamon teal	1	0.88
Redhead	1	4.20

Table 3.—Geometric mean boron concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1987-88 (continued)

	1987	
Location	n	Mean
Canada goose [2]	2	3.30
American coot	2	12.74
Lead Lake		
Dabbling ducks	9	2.27
Mallard	2	3.63
Gadwall	6	2.14
Cinnamon teal	1	1.30
Redhead	2	2.47
Canada goose [2]	4	4.97
American coot	8	8.36
Black-necked stilt	11	2.87
Eared grebe	4	1.58
Foxtail Lake		
Diving ducks	6	1.99
Redhead	4	3.35
Ruddy duck	2	0.70
Cinnamon teal	2	3.54
American coot	6	6.41
Stillwater Point Reservoir		
Redhead	1	1.70
American coot	1	3.30
Eared grebe	3	1.98
Tule Lake		
Dabbling ducks	23	2.31
Mallard	3	2.69
Gadwall	11	2.40
Cinnamon teal	4	2.16
Northern pintail	5	2.04
Eared grebe	9	1.82
Black-necked stilt	11	3.68
Massie/Desert Gun Club		
Canada goose [2]	1	3.21
Areas Combined [3]		
Gadwall	20	2.35

Table 3.—Geometric mean boron concentrations (ppm, dw) in waterbird eggs collected from the Lahontan Valley, Nevada, 1987-88 (concluded)

Location	1987	
	n	Mean
Northern pintail	5	2.04
Diving ducks	35	2.15
Redhead	24	3.07
Ruddy duck	11	0.99
Canada goose[2]	7	4.16
Eared grebe	16	1.79
Black-necked stilt	44	3.05
Northern harrier[4]	2	2.39
American kestrel[4]	1	1.20

Note: Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] Adjacent to Lahontan Valley, but generally not recognized as part of it.

[2] Only Canada goose eggs were collected in 1988.

[3] If no significant difference among locations within a year, the data for a species, or group of species, were combined for that year.

[4] Exact locations not directly related to sites for waterbirds.

Table 4.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Harney Lake						
Dabbling ducks	**17**	**0.58B**	**10**	**0.89A**		
Mallard	6	0.81			6	0.81
Gadwall	**8**	**0.38A**	**8**	**0.83A**	16	0.56
Cinnamon teal	2	1.06	2	1.13	4	1.09
Northern pintail	1	0.73			1	0.73
Redhead	3	0.44	3	1.03	6	0.68
American coot	15	0.43			15	0.43
Black-necked stilt	**19**	**0.97B**	**16**	**1.90A**		
Northern harrier	1	3.85	2	1.45	3	2.00

Table 4.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87 (concluded)

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Malheur Lake						
Dabbling ducks	**14**	**1.04A**	**21**	**1.36A**	35	1.22
Mallard	2	2.05	7	1.42	9	1.54
Gadwall	**8**	**0.66A**	**9**	**1.23A**	17	0.92
Cinnamon teal	3	2.00	5	1.53	8	1.70
Northern pintail	1	1.37			1	1.37
Diving ducks	**6**	**1.22A**	**20**	**0.97A**	26	1.03
Redhead	3	0.78	17	0.88	20	0.87
Ruddy duck	1	0.95			1	0.95
Canvasback[1]	2	2.75	3	1.70	5	2.06
American coot	**5**	**0.49A**	**28**	**0.52A**	33	0.51
Black-necked stilt			16	1.35	16	1.35
Eared grebe			10	2.37	10	2.37
White-faced ibis			10	2.98	10	2.98
Northern harrier	**5**	**2.06A**	**6**	**1.25B**		
Areas Combined[2]						
Mallard	**8**	**1.02A**	**7**	**1.42A**	15	1.19
Gadwall	**16**	**0.50B**	**17**	**1.02A**		
Cinnamon teal	**5**	**1.56A**	**7**	**1.40A**	12	1.47
Northern pintail	2	1.00			2	1.00
Diving ducks	**9**	**0.87A**	**23**	**0.98A**	32	0.95
Redhead	**6**	**0.59A**	**20**	**0.90A**	26	0.82
Ruddy duck	1	0.95			1	0.95
Canvasback	2	2.75	3	1.70	5	2.06
American coot	**20**	**0.44A**	**28**	**0.52A**	48	0.48
Black-necked stilt	**19**	**0.97B**	**32**	**1.60A**		
Eared grebe			10	2.37	10	2.37
White-faced ibis			10	2.98	10	2.98
Northern harrier	**6**	**2.29A**	**8**	**1.30B**		

Note: Statistical tests conducted (**BOLD**) between years when sample size five eggs (one egg per nest). Means within each row sharing a letter are not significantly different, $P > 0.05$ (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] *Aythya valisineria.*

[2] If no significant difference among locations within a year, the data for a species, or group of species, were combined for that year.

significantly higher concentrations in 1986 than in 1987. Mallards, cinnamon teal, redheads, diving ducks (mostly redheads), and American coots showed no significant difference between 1986 and 1987.

When adequate numbers of eggs were analyzed for mercury at Harney Lake (table 5), gadwall and dabbling ducks (mostly gadwall) contained significantly higher mercury concentrations in 1987 than in 1986 (0.15 vs. 0.08 ppm and 0.23 vs. 0.07 ppm). Between 1986 and 1987, no significant differences in mercury concentrations were found in eggs at Malheur Lake, although only dabbling ducks could be compared because an insufficient number of eggs were collected in 1986. Only gadwalls showed a significant difference in 1987 between Harney Lake (0.15 ppm) and Malheur Lake (0.09 ppm). Three other comparisons between Harney Lake and Malheur Lake (dabbling ducks, 1986; dabbling ducks, 1987; and black-necked stilts, 1987) were not significantly different. Therefore, all mercury data (except gadwall and dabbling ducks [which included gadwalls] in 1987) from both locations at Malheur NWR were combined and compared between years. No significant differences were found between years for the combined data.

Fewer eggs were analyzed for boron in 1986 than were analyzed for selenium or mercury, which almost eliminated the option to conduct statistical tests between 1986 and 1987 (table 6). The only test between years that could be conducted was for dabbling ducks at Harney Lake, and no significant difference was found in boron concentrations between 1986 and 1987 (2.49 vs. 3.24 ppm). Three statistical comparisons were made between Malheur Lake and Harney Lake in 1987, with gadwall (3.28 vs. 4.12 ppm) and black-necked stilts (3.75 vs. 4.76 ppm) showing no significant differences. However, dabbling duck eggs in 1987 contained significantly more boron at Harney Lake (3.24 ppm) than at Malheur Lake (1.52 ppm). Therefore, all boron data (except dabbling ducks in 1987) from both locations at Malheur NWR were combined and compared between 1986 and 1987. American coot eggs contained higher concentrations in 1986 (4.70 ppm) than in 1987 (2.61 ppm); however, the significant difference appeared to be because seven eggs (6.40 ppm) were collected at Harney Lake in 1986 and none were collected there in 1987.

Green River and Vicinity, Wyoming and Utah.—The upper and middle Green River included two NWRs (Seedskadee and Ouray), immediately adjacent to the river. The Green River also flows through Stewart Lake during spring runoff in most years. The other locations were in the vicinity, but not directly associated with the Green River. Eggs were collected at these sites only in 1988, with most from Seedskadee NWR. Few statistical tests could be conducted, although dabbling duck eggs contained significantly higher selenium concentrations at Ouray NWR (4.54 ppm) and the Big Sandy River (4.23 ppm) than further upstream on the Green River at Seedskadee NWR (1.36 ppm) (table 7). The few duck eggs collected at Stewart Lake, near Ouray NWR, also contained high selenium concentrations. American coots were not sampled at Ouray NWR or Stewart Lake in Utah, and all locations sampled in Wyoming contained nearly equal selenium concentrations (means of 1.13 to 1.48 ppm). Black-crowned night-heron (5.03 ppm), double-crested cormorant (*Phalacrocorax auritus*) (3.68 ppm), eared grebe (2.80 ppm), and white-faced ibis (2.79 ppm) eggs collected in Wyoming contained generally higher selenium concentrations than the eggs of ducks (except those along the Big Sandy River), geese, or coots.

Table 5.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Harney Lake						
Dabbling ducks	**10**	**0.07B**	**10**	**0.23A**		
Mallard	3	0.06			3	0.06
Gadwall	**5**	**0.08B**	**8**	**0.15A**		
Cinnamon teal	1	0.13	2	1.12	3	0.55
Northern pintail	1	0.03			1	0.03
Redhead	1	0.08	3	0.17	4	0.14
American coot	8	0.19			8	0.19
Black-necked stilt	**11**	**0.82A**	**16**	**0.49A**	27	0.60
Northern harrier	1	1.08	2	0.25	3	0.41
Malheur Lake						
Dabbling ducks	**5**	**0.10A**	**21**	**0.15A**	26	0.14
Mallard	1	0.03	7	0.15	8	0.12
Gadwall	3	0.23	9	0.09	12	0.12
Cinnamon teal	1	0.03	5	0.32	6	0.22
Diving ducks	3	0.06	20	0.24	23	0.20
Redhead	2	0.09	17	0.24	19	0.22
Canvasback	1	0.03	3	0.21	4	0.13
American coot	3	0.10	28	0.25	31	0.23
Black-necked stilt			16	0.38	16	0.38
Eared grebe			10	0.22	10	0.22
White-faced ibis			10	0.47	10	0.47
Northern harrier	2	1.31	6	0.35	8	0.49
Areas Combined [1]						
Dabbling ducks	15	0.08			15	0.08
Mallard	4	0.05	7	0.15	11	0.10
Gadwall	8	0.12			8	0.12
Cinnamon teal	2	0.06	7	0.46	9	0.30
Northern pintail	1	0.03			1	0.03
Diving ducks	4	0.07	23	0.23	27	0.19
Redhead	3	0.09	20	0.23	23	0.20
Canvasback	1	0.03	3	0.21	4	0.13
American coot	**11**	**0.16A**	**28**	**0.25A**	39	0.22
Black-necked stilt	**11**	**0.82A**	**32**	**0.43A**	43	0.51

Table 5.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87 (concluded)

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Eared grebe			10	0.22	10	0.22
White-faced ibis			10	0.47	10	0.47
Northern harrier	3	1.23	8	0.32	11	0.46

Note: Statistical tests conducted (**BOLD**) between years when sample size five eggs (one egg per nest). Means within each row sharing a letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] If no significant difference among locations within a year, the data for a species, or group of species, were combined for that year.

Table 6.—Geometric mean boron concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Harney Lake						
Dabbling ducks	**5**	**2.49A**	**10**	**3.24A**	15	2.97
Mallard	1	4.00			1	4.00
Gadwall	2	2.00	8	4.12	10	3.57
Cinnamon teal	1	2.00	2	1.24	3	1.45
Northern pintail	1	3.00			1	3.00
Redhead			3	3.47	3	3.47
American coot	7	6.40			7	6.40
Black-necked stilt	1	3.00	16	4.76	17	4.64
Northern harrier			2	2.33	2	2.33
Malheur Lake						
Dabbling ducks	3	2.88	21	1.52	24	1.65
Mallard			7	0.92	7	0.92
Gadwall	1	4.00	9	3.28	10	3.35
Cinnamon teal	2	2.45	5	0.77	7	1.07
Diving ducks			20	2.49	20	2.49
Redhead			17	2.66	17	2.66
Canvasback			3	1.72	3	1.72
American coot	3	2.29	28	2.61	31	2.58
Black-necked stilt			16	3.75	16	3.75

Table 6.—Geometric mean boron concentrations (ppm, dw) in waterbird eggs collected from Malheur NWR, Oregon, 1986-87 (concluded)

Location	1986		1987		Combined	
	n	Mean	n	Mean	n	Mean
Eared grebe			10	4.08	10	4.08
White-faced ibis			10	1.76	10	1.76
Northern harrier			6	1.43	6	1.43
Areas Combined [1]						
Dabbling ducks	8	2.63				
Mallard	1	4.00	7	0.92	8	1.10
Gadwall	3	2.52	17	3.65	20	3.45
Cinnamon teal	3	2.29	7	0.88	10	1.17
Northern pintail	1	3.00			1	3.00
Diving ducks			23	2.60	23	2.60
Redhead			20	2.77	20	2.77
Canvasback			3	1.72	3	1.72
American coot	**10**	**4.70A**	**28**	**2.61B**		
Black-necked stilt	1	3.00	32	4.22	33	4.18
Eared grebe			10	4.08	10	4.08
White-faced ibis			10	1.76	10	1.76
Northern harrier			8	1.61	8	1.61

Note: Statistical tests conducted (**BOLD**) between years when sample size five eggs (one egg per nest). Means within each row sharing a letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] If no significant difference among locations within a year, the data for a species, or group of species, were combined for that year.

Table 7.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected along the Green River and vicinity, Wyoming and Utah, 1988

Species	Willis Ranch Bear River		Seedskadee NWR		Big Sandy River		Ouray NWR		Stewart Lake		Old Eden Reservoir		Ocean Lake Riverton		Areas Combined[1]	
	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Dabbling ducks			**16**	**1.36B**	**5**	**4.23A**	**15**	**4.54A**	3	13.31						
Mallard			1	2.10	3	3.95	5	5.18	1	9.55					10	4.64
Gadwall			**6**	**1.25B**	1	5.50	**5**	**3.78A**								
Cinnamon teal			9	1.36			3	3.51	2	15.72					14	2.37
Northern pintail					1	4.00	1	12.30							2	7.01
Northern shoveler							1	6.70							1	6.70
Diving ducks	**11**	**1.83A**	**18**	**1.48A**					2	15.81	**5**	**1.24A**	2	0.72	38	1.68
Redhead	**5**	**1.87A**	**11**	**1.59A**					2	15.81	2	0.97			20	1.99
Ruddy duck	**5**	**1.84A**	**7**	**1.32A**							3	1.47	2	0.72	17	1.38
Canvasback	1	1.60													1	1.60
American coot	**22**	**1.14A**	**17**	**1.48A**							**15**	**1.13A**	**13**	**1.31A**	67	1.25
White-faced ibis	10	2.79													10	2.79
Eared grebe											24	2.80			24	2.80
Double-crested cormorant													20	3.68	20	3.68
Canada goose			**6**	**1.59A**							**5**	**1.10A**	4	1.92	15	1.48
Black-crowned night-heron											7	5.03			7	5.03
American avocet											2	2.14			2	2.14
Black-necked stilt											1	2.00			1	2.00
Northern harrier					2	1.74									2	1.74

Note: Statistical tests conducted (**Bold**) among locations when sample size five eggs (one egg per nest). Rows with means sharing the same letter are not significantly different, $P > 0.05$ (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] If no significant differences among locations, the data for a species, or group of species, were combined.

Mercury concentrations in the Wyoming and Utah study areas in 1988 were generally low (table 8). The highest concentrations at locations with at least five eggs collected included double-crested cormorants at Ocean Lake (1.41 ppm) and black-crowned night-herons at Old Eden Reservoir (1.19 ppm). Although the mercury concentrations were low, statistically significant differences among locations were found for a few species or groups of ducks. For example, dabbling ducks contained significantly higher concentrations at Seedskadee NWR (0.40 ppm) and Big Sandy River (0.32 ppm) than further downstream at Ouray NWR (0.10 ppm). Diving ducks contained significantly higher mercury concentrations at Willis Ranch/Bear River (0.15 ppm) and Seedskadee NWR (0.09 ppm) than at Old Eden Reservoir (0.02 ppm). A large series of American coot eggs from the four locations in Wyoming showed the highest mercury concentrations at Ocean Lake (0.44 ppm), followed by Willis Ranch/Bear River (0.25 ppm), Seedskadee NWR (0.21 ppm), and Old Eden Reservoir (0.06 ppm). The coot eggs collected at Ocean Lake contained significantly higher mercury concentrations than at Seedskadee NWR and Old Eden Reservoir (table 8).

Boron was analyzed in eggs from Wyoming and Utah, with a relatively high detection limit of 2.0 ppm. Only 23 of the 218 eggs contained concentrations above the detection limit. Only 16 of 67 (24%) American coot, 2 of 15 (13%) Canada goose, and 5 of 24 (21%) eared grebe eggs contained boron concentrations above 2 ppm. Fifteen of the 16 American coot eggs with concentrations above the detection limit were collected at Old Eden Reservoir (range from 6 to 12 ppm) with the remaining egg collected at Seedskadee NWR (3 ppm). The five eared grebe eggs (3 to 8.8 ppm) and one Canada goose egg (6 ppm) also came from Old Eden Reservoir. The other Canada goose egg came from Seedskadee NWR (2.5 ppm). No mallard, cinnamon teal, gadwall, redhead, ruddy duck (*Oxyura jamaicensis*), black-crowned night-heron, white-faced ibis, double-crested cormorant, or northern harrier eggs contained detectable concentrations of boron.

Benton Lake NWR and Freezeout Lake GMA, Montana.—Although substantial numbers of duck eggs were collected from the various units at Benton Lake in 1989, no significant differences in selenium concentrations were found among units for any duck species (table 9). Therefore, dabbling duck eggs for each species for all units were combined at Benton Lake and evaluated to determine if statistically significant differences existed among species. Gadwall eggs (units combined) contained significantly higher selenium concentrations (4.39 ppm) than mallards (2.37 ppm), northern pintails (*Anas acuta*) (2.29 ppm), and cinnamon teal (2.05 ppm).

Of special interest was a comparison of selenium egg residue concentrations between birds nesting at Benton Lake and Freezeout Lake GMA, which is about 30 km to the northwest of Benton Lake. Only three comparisons could be made: (1) cinnamon teal showed no significant difference (2.05 vs. 1.83 ppm), (2) lesser scaup (*Aythya affinis*) showed no significant difference (2.52 vs. 1.86 ppm), but (3) dabbling ducks (without gadwalls) showed a significant difference (2.27 vs. 1.56 ppm). In all three cases, mean Benton Lake NWR selenium concentrations were higher (though not always statistically significant) than at Freezeout Lake.

When egg concentrations from seep areas at Benton Lake NWR were compared with eggs from nonseep areas, only the mallard showed significantly higher selenium concentrations near seeps (4.23 vs. 1.74 ppm) (table 10). However, cinnamon teal, northern pintail, and lesser scaup showed the same pattern, though not statistically

Table 8.—Geometric mean mercury concentrations (ppm, dw) in waterbird eggs collected along the Green River and vicinity, Wyoming and Utah, 1988

Species	Willis Ranch Bear River		Seedskadee NWR		Big Sandy River		Ouray NWR		Stewart Lake		Old Eden Reservoir		Ocean Lake Riverton		Areas Combined[1]	
	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Dabbling ducks			**16**	**0.40A**	**5**	**0.32A**	**15**	**0.10B**	3	0.07						
Mallard			1	0.19	3	0.38	5	0.04	1	0.03					10	0.09
Gadwall			**6**	**0.21A**	1	0.37	**5**	**0.11A**							12	0.17
Cinnamon teal			9	0.67			3	0.49	2	0.11					14	0.48
Northern pintail					1	0.17	1	0.04							2	0.08
Northern shoveler							1	0.17							1	0.17
Diving ducks	**11**	**0.15A**	**18**	**0.09A**					2	0.02	**5**	**0.02B**	2	0.12		
Redhead	**5**	**0.16A**	**11**	**0.07A**					2	0.02	2	0.01			20	0.08
Ruddy duck	**5**	**0.20A**	**7**	**0.12A**							3	0.03	2	0.12	17	0.11
Canvasback	1	0.02													1	0.02
American coot	**22**	**0.25AB**	**17**	**0.21B**							**15**	**0.06C**	**13**	**0.44A**		
White-faced ibis	10	0.43													10	0.43
Eared grebe											24	0.20			24	0.20
Double-crested cormorant													20	1.41	20	1.41
Canada goose			**6**	**0.02A**							**5**	**0.01A**	4	0.01	15	0.01
Black-crowned night-heron											7	1.19			7	1.19
American avocet											2	0.19			2	0.19
Black-necked stilt											1	4.20			1	4.20
Northern harrier					2	0.08									2	0.08

Note: Statistical tests conducted (**Bold**) among locations when sample size five eggs (one egg per nest). Rows with means sharing the same letter are not significantly different, $P > 0.05$ (Tukey's Studentized Range Test). Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were sometimes combined (see below).

[1] If no significant difference among locations, the data for a species, or group of species, were combined.

Table 9.—Geometric mean selenium concentrations (ppm, dw) in waterbird eggs collected at Benton Lake NWR, and Freezeout Lake GMA, Montana, 1989

Species	Benton Lake NWR														Freezeout Lake	
	Unit 1		Unit 2		Unit 3		Unit 4A		Unit 4C		Unit 5/6		Units Combined[1]			
	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Dabbling ducks[2]	4	2.38	**11**	**2.32A**	**11**	**1.94A**	**10**	**2.72A**	**18**	**2.68A**	**14**	**1.75A**	68	2.27	12	1.56
Mallard			4	1.79	2	1.49	**6**	**2.99A**	**10**	**3.25A**	**7**	**1.65A**	29	2.37	3	1.28
Gadwall	**9**	**5.00A**	**10**	**4.59A**	**9**	**5.90A**	**6**	**3.65A**	**9**	**3.86A**	**11**	**3.65A**	54	4.39		
Cinnamon teal	1	2.52	3	2.40	2	2.19	1	1.37	**5**	**2.00A**	**5**	**1.96A**	17	2.05	5	1.83
Northern pintail			4	2.94	7	2.02	3	2.84	2	2.16	2	1.66	18	2.29	2	1.57
Northern shoveler	3	2.34							1	2.60			4	2.40	1	1.49
American wigeon[3]															1	1.35
Redhead					1	1.90							1	1.90		
Lesser scaup	2	3.63	4	1.95	1	2.32	5	2.53	3	3.26	1	1.68	16	2.52	10	1.86
Eared grebe									10	5.65			10	5.65		
Northern harrier									3	2.97			3	2.97		
Short-eared owl[4]															1	3.40

Note: Statistical tests conducted (**BOLD**) among locations when sample size five eggs (one egg per nest). Rows with means sharing the same letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test). Dabbling ducks represent a feeding strategy; species in the group were sometimes combined (see below).

[1] If no significant difference among locations at Benton Lake, the data for a species, or group of species, were combined.

[2] Excludes gadwall because they contained significantly higher selenium concentrations than the other dabbling ducks.

[3] *Anas americana.*

[4] *Asio flammeus.*

Table 10.—A comparison of selenium concentrations (ppm, dw) in duck eggs collected near seep and nonseep areas at Benton Lake NWR, 1989

Species	Seep areas		Nonseep areas	
	n	Mean	n	Mean
Mallard	**10**	**4.23A**	**19**	**1.74B**
Gadwall	**6**	**4.24A**	**48**	**4.41A**
Cinnamon teal	**5**	**2.34A**	**12**	**1.95A**
Northern pintail	2	3.59	16	2.17
Lesser scaup	2	4.56	14	2.32

Note: Statistical tests conducted (**BOLD**) among locations when sample size five eggs (one egg per nest). Rows with means sharing the same letter are not significantly different, P > 0.05 (Tukey's Studentized Range Test).

significant. The late nesting gadwall was the only exception, with nearly identical concentrations at both locations.

Comparison of Trace Elements in Eggs Among Locations

Gadwall, American coots, black-necked stilts, and eared grebes were the species most commonly studied and were chosen for statistical comparison of selenium, mercury, and boron concentrations among refuges (tables 11, 12, 13). Gadwall eggs contained significantly higher selenium concentrations at Benton Lake NWR (4.39 ppm) and Ouray NWR (3.78 ppm), and much lower concentrations at Seedskadee NWR (1.25 ppm), the Lahontan Valley (0.75 to 1.55 ppm), and Malheur NWR (0.50 to 1.02 ppm) (table 11). American coots were not sampled at either Benton Lake or Ouray NWRs. Although statistically significant differences were detected among the locations sampled, selenium concentrations were all within a narrow range (0.44 to 1.27 ppm). Black-necked stilt eggs were available only from Malheur NWR and several locations within the Lahontan Valley. The highest selenium concentrations were reported at Humboldt/Toulon (3.65 ppm) in 1987. With the exception of Humboldt/Toulon, geometric mean selenium concentrations in black-necked stilts varied from 0.80 to 2.36 ppm. Eared grebe eggs consistently contained higher selenium concentrations than eggs from other species, and the highest concentrations were reported at Benton Lake (5.65 ppm) and the Lahontan Valley in 1987 (4.42 ppm).

Mercury concentrations in eggs among refuges (table 12) were evaluated in the same manner as selenium, although mercury was not investigated at Benton Lake NWR. All four species evaluated (gadwall, American coots, black-necked stilts, and eared grebes) showed the highest mercury concentrations in the Lahontan Valley. Eggs from all locations outside the Lahontan Valley of Nevada showed some statistically significant differences, with mercury concentrations varying within a relatively narrow range (0.06 to 0.82 ppm).

Boron was evaluated in eggs from the Lahontan Valley and Malheur NWR (table 13). Black-necked stilt eggs (4.22 vs. 3.05 ppm) and eared

Table 11.—A comparison of selenium concentrations (ppm, dw) in waterbird eggs among refuges, 1986-89

Location	Gadwall		American coot		Black-necked stilt		Eared grebe	
	n	Mean	n	Mean	n	Mean	n	Mean
Lahontan Valley, NV								
1986	14	0.75CD						
1987	20	1.44B	43	0.68BC			16	4.42AB
1988	21	1.55B	30	1.27A			30	3.73B
Carson Lake, NV								
1986			15	0.60BC	24	0.80E	11	2.36D
1987					10	1.05DE		
1988					7	1.70BCD		
Lead Lake, NV								
1986			9	0.93AB				
1987					11	1.16DE		
1988					19	2.04BC		
Stillwater Point Reservoir, NV								
1986			5	1.02AB				
Humboldt/Toulon, NV								
1987					12	3.65A		
Tule Lake, NV								
1986					6	1.29CDE		
1987					11	1.21DE		
1988					14	2.36AB		
Foxtail Lake, NV								
1986							10	3.45BC
Malheur NWR, OR								
1986	16	0.50D	20	0.44C	19	0.97E		
1987	17	1.02BC	28	0.52C	32	1.60BCD	10	2.37D
Seedskadee NWR, WY								
1988	6	1.25BC	67	1.25A[1]				
Ouray NWR, UT								
1988	5	3.78A						
Old Eden Reservoir, WY								
1988							24	2.80CD
Benton Lake NWR, MT								
1989	54	4.39A					10	5.65A

Note: Columns with means showing the same letters are not significantly different, $P > 0.05$ (Tukey's Studentized Range Test). When significant differences were detected among locations at a refuge during a given year in earlier tests, they were presented separately here.

[1] Includes other eggs from western Wyoming (see table 7).

Table 12.—A comparison of mercury concentrations (ppm, dw) in waterbird eggs among refuges, 1986-88

Location	Gadwall		American coot		Black-necked stilt		Eared grebe	
	n	Mean	n	Mean	n	Mean	n	Mean
Lahontan Valley, NV								
1986	14	0.57AB			34	2.59AB	21	1.07A
1987	20	0.19BC					16	1.19A
1988	21	1.76A	30	1.69A			30	1.27A
Carson Lake, NV								
1986			15	1.43AB				
1987			15	0.87ABC	10	0.87CD		
1988					7	3.65A		
Sheckler Reservoir, NV								
1987			7	0.32DEF				
Lead Lake, NV								
1986			9	0.74ABC				
1987			8	0.88ABC	11	0.86CD		
1988					16	1.50ABC		
Foxtail Lake, NV								
1987			6	0.61BCD				
Stillwater Point Reservoir, NV								
1986			5	1.50A				
Tule Lake								
1987					11	0.19E		
1988					14	1.44BC		
Malheur NWR, OR								
1986	8	0.12C	11	0.16F	11	0.82CD		
1987			28	0.25EF	32	0.43DE	10	0.22B
Malheur Lake, OR								
1987	9	0.09C						
Harney Lake, OR								
1987	8	0.15C						
Seedskadee NWR, WY								
1988	6	0.21BC	17	0.21EF				
Ouray NWR, UT								
1988	5	0.11C						

Table 12.—A comparison of mercury concentrations (ppm, dw) in waterbird eggs among refuges, 1986-88 (concluded)

Location	Gadwall		American coot		Black-necked stilt		Eared grebe	
	n	Mean	n	Mean	n	Mean	n	Mean
Old Eden Reservoir, WY								
1988			15	0.06G			24	0.20B
Willis Ranch/Bear River, WY								
1988			22	0.25EF				
Ocean Lake/Riverton, WY								
1988			13	0.44CDE				

Note: Columns with means showing the same letters are not significantly different, P > 0.05 (Tukey's Studentized Range Test). When significant differences were detected among locations at a refuge during a given year in earlier tests, they were presented separately here.

Table 13.—A comparison of boron concentrations (ppm, dw) in waterbird eggs among refuges, 1986-87

Location	Gadwall		American coot		Black-necked stilt		Eared grebe	
	n	Mean	n	Mean	n	Mean	n	Mean
Lahontan Valley, NV								
1987	20	2.35A			44	3.05B	16	1.79B
Carson Lake, NV								
1987			15	5.93AB				
Sheckler Reservoir, NV								
1987			7	2.67BC				
Lead Lake, NV								
1987			8	8.36A				
Foxtail Lake, NV								
1987			6	6.41A				
Malheur NWR, OR								
1986			10	4.70ABC				
1987	17	3.65A	28	2.61C	27	4.22A	10	4.08A

Note: Columns with means showing the same letters are not significantly different, P > 0.05 (Tukey's Studentized Range Test). When significant differences were detected among locations at a refuge during a given year in earlier tests, they were presented separately here.

grebe eggs (4.08 vs. 1.79 ppm) contained significantly higher boron concentrations at Malheur NWR than in the Lahontan Valley, and gadwall eggs showed no significant difference (3.65 vs. 2.35 ppm). Boron concentrations in American coot eggs were variable among locations from the Lahontan Valley and between years at Malheur NWR. Coot eggs at Malheur NWR in 1986 (4.70 ppm) were not significantly different from eggs in the Lahontan Valley sites in 1987 (2.67 to 8.36 ppm). However, Malheur in 1987 (2.61 ppm) was significantly lower than at most 1987 Lahontan Valley collection sites.

Organochlorine Contaminants in Eggs.—Species higher in the food chain than waterfowl (e.g., herons, egrets, ibis, grebes and stilts) were evaluated for OCs in their eggs because they were either more likely to bioaccumulate pesticides because of their diet or elevated OCs were previously reported from their eggs. Our concern was that possible adverse effects of these contaminants could confound effects caused by trace elements. Fortunately, critical OC concentrations in eggs were available from the literature for three of the five species studied.

Lahontan Valley, Nevada.—OC pesticides, their metabolites, and PCBs in waterbird eggs collected in 1988 are shown in table 14. DDE caused reproductive problems in the past for the white-faced ibis (Henny and Herron, 1989), the black-crowned night-heron (Henny et al., 1984), and the snowy egret (Findholt, 1984; Henny et al., 1985) in the Intermountain West.

White-faced ibis eggs at Carson Lake and the Canvasback Club near Stillwater WMA in 1988 (table 14) contained DDE concentrations similar to those reported at Carson Lake between 1980 and 1986 (Henny and Herron, 1989). Twelve of 31 (39%) eggs in 1988 contained DDE concentrations above the critical 4 ppm, which is nearly identical to the 73 of 201 (36%) eggs collected between 1980 and 1986 in the Lahontan Valley (Henny and Herron, 1989). In 1996, 9 of 20 (45%) white-faced ibis eggs were above the critical 4-ppm DDE at Carson Lake (Henny, 1997). Based upon the above information, DDE continues to adversely affect productivity of white-faced ibis in the Lahontan Valley.

The black-crowned night-heron is less sensitive to DDE than the white-faced ibis (critical concentration, 8 ppm instead of 4 ppm [see Henny et al., 1984]). Only 1 of 11 (9%) black-crowned night-heron eggs collected in 1988 contained more than 8 ppm, whereas 4 of 7 eggs (57%) contained more in 1980 (Henny et al., 1984). With the exception of black-crowned night-heron colonies along the Columbia River, DDE residues declined in the Intermountain West between 1979 and 1980 (Malheur NWR, Oregon, 4.70 vs. 2.73 ppm; Ruby Valley, Nevada, 8.21 vs. 4.13 ppm). Although few eggs were collected at sites on Stillwater WMA in 1980 (7 eggs) and 1988 (11 eggs), the geometric mean concentration of DDE in the eggs followed the same overall pattern of decline (5.08 vs. 2.43 ppm) (table 14). Black-crowned night-heron egg residues in 1988 imply that DDE was still negatively impacting production rates, although not as severely. More recently, Henny (1997) reported a geometric mean of 0.90-ppm DDE (8 eggs) in black-crowned night-heron eggs collected in 1996 at Carson Lake; no egg residues were above 8 ppm.

The snowy egret is intermediate (between white-faced ibis and black-crowned night-herons) in sensitivity to DDE. The concentration of DDE in snowy egret eggs becomes critical above 5 ppm (see Findholt, 1984; Henny et al., 1985). Eggs collected at Stillwater WMA sites between 1981 and 1983 included 9 of 42 (21%) above 5-ppm DDE. There was no significant difference in

Table 14.—Organochlorine contaminants (geometric mean, ppm, ww) in eggs of white-faced ibis, black-crowned night-heron, black-necked stilt, and snowy egret from Lahontan Valley, Nevada, and Green River and vicinity, Wyoming, 1988

Category	(N)	DDE above critical level	Geometric mean (high value)									
		No. eggs (%)	DDE	DDT	DDD	Dieldrin	HE	Chlordane(t)	Toxaphene	HCB	-HCH	PCB
Lahontan Valley, NV												
White-faced ibis												
Carson Lake												
	(10)[1]	2 (20%)[2]	0.53 (8.8)	0.019 (0.24)	(0.04)	(0.23)	(0.01)	0.035 (0.065)	(2.75)	(0.04)		
	(10)[3]	5 (50%)[2]	1.95 (10.0)	0.077 (0.51)	(0.02)	0.023 (0.15)	0.027 (0.11)	0.053 (0.135)	0.61 (5.53)	0.020 (1.6)	0.011 (0.32)	0.051 (0.14)
Canvasback Club												
	(11)[4]	5 (45%)[2]	2.51 (13.3)	0.13 (1.28)	(0.08)	0.049 (0.25)	0.025 (0.96)	0.069 (0.52)	0.78 (11.56)	0.037 (2.6)	(0.07)	
Black-crowned night-heron												
Lead Lake												
	(11)	1 (9%)[5]	2.43 (12.04)	0.25 (0.06)	(0.01)	(0.05)	0.011 (0.08)	0.050 (0.095)	(1.72)	(0.01)	(0.27)	0.293 (0.82)
Snowy egret												
Canvasback Club												
	(10)	2 (20%)[6]	1.91 (16.77)	0.034 (1.24)	0.013 (0.18)	(0.17)	0.011 (0.09)	0.046 (0.13)	(0.93)	0.009 (0.02)	0.025 (0.32)	(0.50)
Black-necked stilt												
Lead Lake-Nutgrass												
	(7)	--	1.18 (13.55)	(0.01)		0.013 (0.03)	(0.04)	0.008 (0.017)		0.019 (0.11)	0.016 (0.33)	(0.50)
Carson Lake												
	(3)	--	1.25 (3.06)	0.020 (0.17)	(0.01)	(0.01)	0.014 (0.06)	0.057 (0.115)		0.011 (0.03)	0.054 (0.23)	
Eared grebe												
Lead Lake												
	(10)	--	0.23 (2.25)								(0.01)	
Green River, WY												
Eared grebe												
Old Eden Reservoir												
	(10)	--	0.19 (0.56)					(0.02)		0.01 (0.14)		

[1] Early collection - 4/24/88. [2] > 4 ppm. [3] Late collection - 6/3/88. [4] Collected 5/19/88. [5] % > 8 ppm. [6] % > 5 ppm.
<50% above the detection limit, no mean calculated (high value).

Notes: Chlordane(t) = sum of Oxychlordane, -Chlordane, -Chlordane, *cis*-Nonachlor, and *trans*-Nonachlor. Compounds included in analysis but not showing detectable residues were: -BHC, -BHC, -BHC, and Mirex. Rarely detected residue (range ppm)

o,p'-DDE: 3 night-herons, (0.02-0.06); 2 ibis, Carson Lake early (0.02-0.03), Carson Lake late (0.01-0.02); 3 ibis, Canvasback Club (0.02-0.03)
o,p'-DDD: 1 egret (0.01)
o,p'-DDT: 1 egret (0.11)

geometric means among years (1.43, 1.91, and 0.63 ppm, respectively). Little or no change has occurred over time. The geometric mean of DDE in eggs in 1988 was 1.91 ppm, and the percentage of eggs above 5 ppm was a nearly identical 20 percent (2 of 10) (table 14). These data suggest DDE was continuing to negatively influence snowy egret reproductive success.

Black-necked stilt eggs were also collected at Carson Lake between 1980 and 1983 (10 eggs each year) (Henny et al., 1985). DDE in the 40 eggs collected in the early 1980s showed a pattern of decrease over the 4 years (geometric means, 3.26, 1.96, 1.94, and 1.38 ppm, respectively), and the presence of the parent-DDT decreased from 6 of 10 eggs in 1980 to 0 of 10 eggs in 1983. No relationship between DDE and eggshell thickness was documented (Henny et al., 1985); the eggshell thickness was similar to the pre-DDT era. DDE in the 10 eggs collected in 1988 was slightly lower (geometric means, 1.25 ppm, Carson Lake; 1.18 ppm, Lead Lake/Nutgrass; combined, 1.20 ppm) (table 14) than in earlier years (figure 7). With a downward trend in DDE observed and no significant eggshell thinning, it is doubtful that DDE was adversely affecting black-necked stilt reproduction during this study.

Eared grebe eggs were collected at Lead Lake on the Stillwater WMA in 1988, but no eggs were collected and analyzed for organochlorines at the site in earlier years. DDE egg concentrations were much lower (geometric mean, 0.23 ppm) in 1988 than reported for any of the other species.

Other OC pesticides and their metabolites and PCBs were commonly detected in the eggs of all species studied (although to a lesser extent in eared grebes), but concentrations were generally low and below known effect levels.

Green River and Vicinity, Wyoming.—Eared grebe eggs were collected at Old Eden Reservoir in 1988, but, again, no eggs were collected and analyzed for OCs at this site in earlier years. DDE residues were extremely low (0.19 ppm) in 1988 and similar to those reported at Stillwater WMA (0.23 ppm) in 1988. In addition, few other OCs were reported in the eggs (table 14).

Hatching Success in the Field (Ducks and Coots).—It became abundantly clear in 1986, at both Malheur NWR and the Lahontan Valley, that nesting success for dabbling ducks was extremely low (table 15). The low success was at least partially the result of extremely high avian and mammalian predation. A sample comparison (excluding the high and the low values for each group) shows that dabbling duck nesting success (0.0404 to 0.3459) was much lower than diving duck success (0.3519 to 0.4288). The higher diving duck nest success generally relates to their propensity to nest over water, and the water provides some protection from predators.

The contrast between Benton Lake NWR and Freezeout Lake GMA in Montana was especially noteworthy. The sites are located within 30 km of each other. The major contrast was that predator control was practiced at Benton Lake but not at Freezeout Lake. Dabbling duck nesting success was about 5-fold higher at Benton Lake than at Freezeout Lake (0.6479 vs. 0.1214), and diving ducks showed a similar pattern (0.3519 vs. 0.0290), except that the difference was closer to 12-fold. Very few diving ducks and dabbling ducks nested over water at these two sites, and a high number of depredated nests were documented at Freezeout Lake (table 15). To further evaluate productivity rates, we need to know the number of young hatched at each successful nest. The number of eggs collected per nest was usually one in 1986 and three in 1987-89. However, some nests had no eggs taken,

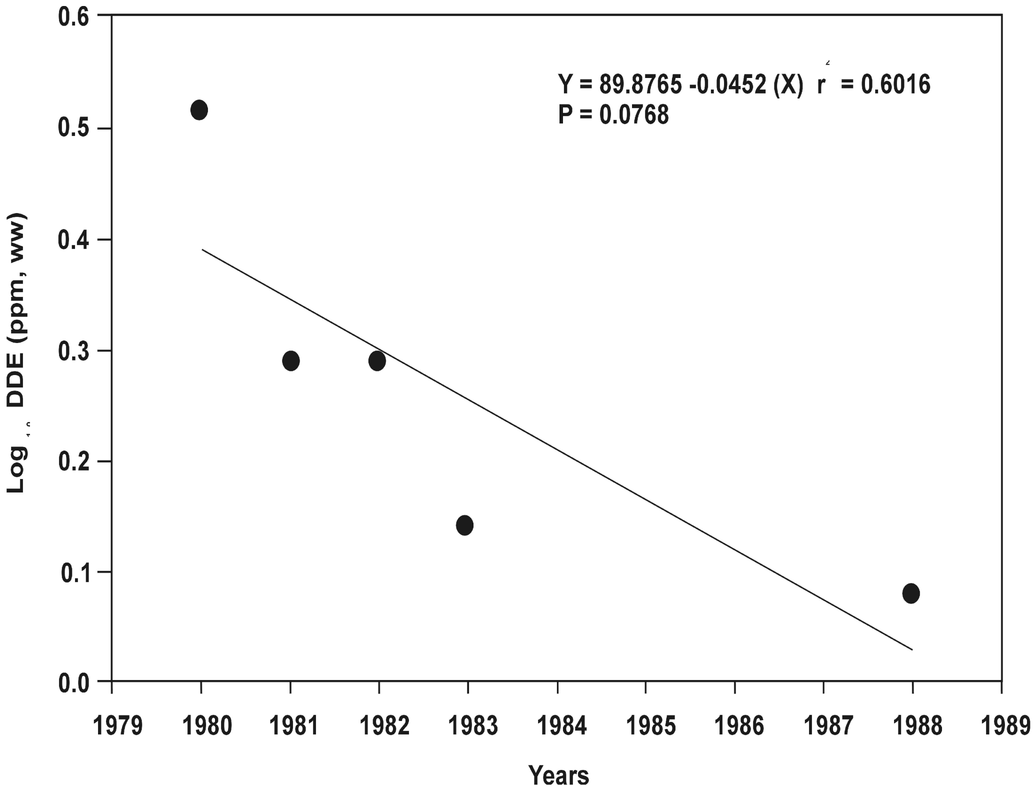


Figure 7.—DDE residues in black-necked stilt eggs from the Lahontan Valley, 1980-88.

hatched at each successful nest by the percentage of successful nests (Mayfield estimate) from table 15, the number of young hatched per nesting attempt was estimated (table 16). The overall success of duck nests was highly variable and depended on local habitat conditions, including water and predator abundance. This variability made it extremely tenuous to evaluate nesting success with respect to possible adverse effects of contaminants in the eggs. Therefore, after the first season of study (1986), it was decided to collect three eggs instead of one from each nest. The one egg was chemically analyzed, and the other two eggs were placed in an incubator for artificial hatching, which essentially eliminated the confounding effects of water conditions, nesting habitat variability, and predators. The success of the two eggs incubated and any anomalies noted could simply be evaluated with respect to contaminant concentrations in the "sample egg" analyzed.

Hatching Success in the Field (Other Species).—Mayfield estimates of nesting success for ducks are frequently found in the literature, but the technique is infrequently used for other species of waterbirds. Therefore, for black-necked stilts (table 17) and eared grebes (table 18), we provide the Apparent Nesting Success (percentage of nesting attempts studied that were successful; i.e., hatched at least one egg) plus Mayfield estimates. If the eggs were all fresh when nests were initially located, Mayfield estimates of nesting success and the Apparent Nesting Success should be similar. At the time the nests were first located, development was categorized into early, middle, and late incubation (1, 2, and 3) in tables 17 and 18. As expected, especially when large numbers of nests were

Table 15.—Mayfield estimates of nesting success for dabbling ducks, diving ducks, and American coots, 1986-89[1]

Location	Number of nests	DSR±SE[2]	Nesting Success	Fate of study nests: Successful[3]	Depredated	Abandoned	Other[4]
Dabbling ducks							
Lahontan Valley, NV							
1986	18	0.8288 ± 0.0445	0.0015	3 (17%)	12 (67%)	3 (17%)	0
1987	74	0.9407 ± 0.0091	0.1214	31 (42%)	36 (49%)	5 (7%)	2 (3%)
1988	64	0.9363 ± 0.0097	0.1032	17 (27%)	45 (70%)	1 (1%)	1 (1%)
Malheur NWR, OR							
1986	39	0.9523 ± 0.0107	0.1852	18 (46%)	15 (38%)	5 (13%)	1 (3%)
1987	25	0.9481 ± 0.0148	0.1590	11 (44%)	10 (40%)	4 (16%)	0
Western WY							
1988	21	0.9112 ± 0.0241	0.0404	5 (24%)	12 (57%)	1 (5%)	3 (14%)
Northern UT							
1988	13	0.9697 ± 0.0128	0.3459	7 (54%)	2 (15%)	2 (15%)	2 (15%)
Benton Lake NWR, MT							
1989	242	0.9875 ± 0.0018	0.6479	192 (79%)	45 (19%)	5 (2%)	0
Freezeout Lake GMA, MT							
1989	22	0.9407 ± 0.0160	0.1214	7 (32%)	15 (68%)	0	0
Diving ducks							
Lahontan Valley, NV							
1986-1988[5]	19	0.9709 ± 0.0102	0.3557	10 (53%)	4 (21%)	5 (26%)	0
Malheur NWR, OR							
1986-1987[5]	25	0.9802 ± 0.0077	0.4966	19 (76%)	2 (8%)	3 (12%)	1 (4%)
Western WY							
1988	17	0.9761 ± 0.0100	0.4288	10 (59%)	6 (35%)	1 (6%)	0

Table 15.—Mayfield estimates of nesting success for dabbling ducks, diving ducks, and American coots, 1986-89[1] (concluded)

Location	Number of nests	DSR±SE[2]	Nesting Success	Fate of study nests: Successful[3]	Depredated	Abandoned	Other[4]
Benton Lake NWR, MT							
1989	47	0.9697 ± 0.0071	0.3519	28 (60%)	10 (21%)	9 (19%)	0
Freezeout Lake GMA, MT							
1989	15	0.9038 ± 0.0267	0.0290	1 (7%)	13 (87%)	1 (7%)	0
American coots							
Lahontan Valley, NV							
1986	35	0.9787 ± 0.0062	0.5242	23 (66%)	11 (31%)	1 (3%)	0
1987	39	0.9259 ± 0.0182	0.0993	25 (64%)	9 (23%)	3 (8%)	2 (5%)
1988	33	0.9972 ± 0.0019	0.9193	30 (91%)	3 (9%)	0	0
Malheur NWR, OR							
1986	19	0.9834 ± 0.0095	0.6052	16 (84%)	3 (16%)	0	0
1987	26	0.9624 ± 0.0116	0.3167	15 (58%)	11 (42%)	0	0
Western WY							
1988	80	0.9848 ± 0.0028	0.6316	54 (68%)	22 (28%)	2 (3%)	2 (3%)

Note: Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were combined.
[1] Parasitized nests were excluded, as well as nests abandoned because of researcher activity.
[2] Daily survival rates.
[3] At least one egg hatched.
[4] Other = destroyed by fire, livestock, weather, etc.
[5] Years combined when n < 10 nests for a year.

Table 16.—Clutch size and number of eggs that hatched from successful nests for dabbling ducks, diving ducks, and American coots, 1986-89[1]

Location	Mean Clutch Size: All eggs ± SD (n)	Mean Clutch Size: After eggs collected	Eggs hatched/ successful nest mean ± SD (n)	Young hatched/ nesting attempt[2]
Dabbling ducks				
Lahontan Valley, NV				
1986	8.27 ± 2.27 (18)	7.27	5.35 ± 2.89 (3)	0.01
1987	7.93 ± 1.92 (74)	6.27	6.32 ± 1.83 (31)	0.77
1988	8.62 ± 1.61 (64)	7.47	4.57 ± 2.88 (17)	0.47
Malheur NWR, OR				
1986	8.21 ± 2.41 (39)	7.34	6.61 ± 2.06 (18)	1.22
1987	8.60 ± 2.02 (25)	6.44	5.82 ± 1.40 (11)	0.93
Western WY				
1988	8.57 ± 1.66 (21)	5.71	6.40 ± 0.55 (5)	0.26
Northern UT				
1988	7.54 ± 1.13 (13)	4.77	4.71 ± 1.11 (7)	1.63
Benton Lake NWR, MT				
1989	9.06 ± 1.95 (242)	7.89	7.30 ± 2.39 (192)	4.73
Freezeout Lake GMA, MT				
1989	8.77 ± 1.60 (22)	7.13	6.85 ± 1.86 (6)	0.83
Diving ducks				
Lahontan Valley, NV				
1986-1988[3]	8.47 ± 2.65 (19)	6.26	4.90 ± 1.91 (10)	1.74
Malheur NWR, OR				
1986-1987[3]	8.16 ± 1.84 (25)	6.20	5.74 ± 1.74 (19)	2.85
Western WY				
1988	9.12 ± 2.74 (17)	6.65	5.44 ± 2.60 (10)	2.33
Benton Lake NWR, MT				
1989	9.37 ± 2.81 (47)	8.69	7.42 ± 2.56 (28)	2.61
Freezeout Lake GMA, MT				
1989	9.13 ± 2.03 (15)	7.13	6.00 (1)	0.17
American coots				
Lahontan Valley, NV				
1986	6.03 ± 2.02 (35)	5.22	5.48 ± 1.97 (23)	2.87
1987	6.05 ± 2.22 (39)	5.15	4.48 ± 1.85 (25)	0.44
1988	6.82 ± 1.49 (33)	6.09	5.73 ± 1.51 (30)	5.27
Malheur NWR, OR				
1986	7.67 ± 1.74 (19)	6.67	6.56 ± 1.79 (16)	3.97
1987	5.96 ± 2.47 (26)	4.92	5.20 ± 1.47 (15)	1.65
Western WY				
1988	7.49 ± 2.43 (80)	6.68	7.39 ± 1.80 (54)	4.67

Note: Dabbling ducks and diving ducks represent two different feeding strategies; species in each group were combined.

[1] Parasitized nests were excluded, as well as nests abandoned because of researcher activity.
[2] Mayfield nesting success (table 15) x eggs hatched per successful nest.
[3] Years combined for n < 10 nests for a year.

Table 17.—Summary of nesting information for the black-necked stilt

Location (year)	Eggs collected	Egg development[1]	Clutch size (n)[2]	Apparent nesting success (n)	Mayfield Estimate: Daily survival mean (95% CI)	Mayfield Estimate: Nesting success[3]
Oregon						
Harney Lake (1986)	May 22-June 4	2	3.75 (8)	62.5 % (8)	0.9406 (0.8725-1.0087)	21.6%
Harney Lake (1987)	May 2-19	1	4.00 (14)	64.3% (14)	0.9816 (0.9653-0.9979)	62.9%
Malheur Lake (1986)	June 3	2	4.00 (11)	100% (11)	All successful	100%
Malheur Lake (1987)	May 3-20	1	3.85 (13)	46.2% (13)	0.9556 (0.9208-0.9903)	32.1%
Nevada						
Lead Lake (1987)	June 6-8	1	4.00 (9)	90.0% (10)	0.9944 (0.9834-1.0054)	86.9%
Lead Lake (1988)	May 16-25	2	4.00 (13)	50.0% (14)	0.9641 (0.9375-0.9907)	40.1%
Carson Lake (1986)	April 30-May 4	1	4.00 (20)	52.0% (25)	0.9632 (0.9425-0.9838)	39.2%
Carson Lake (1987)	May 11	1	3.90 (10)	60.0% (10)	0.9668 (0.9339-0.9998)	43.0%
Carson Lake (1988)	May 31-June 9	2	3.71 (7)	0% (7)	All failed	0%
Tule Lake (1986)	June 3-10	1	N/A	80.0% (10)	0.9907 (0.9777-1.0037)	79.2%
Tule Lake (1988)	May 13-21	1-2	4.00 (16)	87.5% (16)	0.9931 (0.9835-1.0027)	84.1%
Humboldt/Toulon (1987)	May 15	1	4.00 (6)	14.3% (17)	0.8111 (0.6648-0.9573)	0.5%
Pintail Bay (1987)	May 5-22	1	4.00 (10)	70.0% (10)	0.9774 (0.9514-1.0034)	56.5%

[1] At time of egg collection: mostly fresh to early incubation = 1, most a week or more into incubation = 2, most late in incubation = 3.
[2] Clutches all four eggs, except a few with three eggs.
[3] Used 25-day exposure period.

Table 18.—Summary of nesting information for the eared grebe

Location (year)	Eggs collected	Egg development[1]	Clutch size	Apparent nesting success (n)	Mayfield estimate: Daily survival mean (95% CI)	Mayfield estimate: Nesting success[2]
Oregon						
Malheur, Boca Lake (1987)	July 8	3	2.53 (15)	100% (14)	All Successful	100%
Nevada						
Lead Lake (1988)	June 7-14	1	3.17 (23)	82.6% (23)	0.9902 (0.9806-0.9998)	78.9%
East Alkali Lake (1987)	June 30-July 5	2	2.75 (12)	11.1% (9)	0.8813 (0.8042-0.9584)	4.8%
Carson Lake (1986)	June 22	3	3.10 (10)	28.6% (7)	0.9183 (0.8480-0.9885)	12.9%
Foxtail Lake (1986)	June 25	1	3.90 (10)	71.4% (7)	0.9789 (0.9496-1.0082)	59.9%
Wyoming						
Old Eden Reservoir (1988)	May 30 -June 6	1	2.88 (17)	0% (17)	All Failed	0%

[1] At time of egg collection: most fresh to early incubation = 1, most a week or more into incubation = 2, most late in incubation = 3.
[2] Used 24-day exposure period (21 days for incubation, plus 3 days for laying).

available. The clutch size after egg collection provides a useful number that represents the maximum number of eggs that could hatch in the field. Then, by multiplying the number of young nests of black-necked stilts and eared grebes in category 1 (early incubation) had slightly lower nest success based on Mayfield estimates than based on the Apparent Nesting Success (estimates based on a series of 10 nests or more were 7.6 percentage points lower). Most stilt nests were initially found relatively early in incubation during this study.

The black-necked stilt invariably lays 4-egg clutches, and, in this study, 130 of 137 nests contained the usual 4 eggs; the other 7 nests contained 3 eggs, with an overall mean of 3.95 eggs (table 17). Nests destroyed before a final clutch size could be determined were excluded from the clutch size evaluation. It is suspected that the few three-egg clutches had an undetected egg lost before the first nest visit or between visits. Mayfield estimates of black-necked stilt nesting success at Malheur NWR, Oregon, and the Lahontan Valley, Nevada, varied tremendously among years and among locations. The two extremes were 0% success at Carson Lake (1988) and 100% success at Malheur Lake (1986). Black-necked stilts nest in colonies near water and prefer shallow, flooded areas. The nest is on a plant tuft or tussock in the water or on mud by the water's edge. Nesting conditions may change through fluctuations of the water level during the nesting cycle. Therefore, the species nests in an extremely unstable habitat. The reason for the extremely low success at some sites was that the nests flooded, and at other sties, the water surrounding the nests dried up. Flooding seemed to be the more common reason during this study.

Eared grebes were studied in Oregon at Boca Lake, which is located about 11 km north-northeast of Frenchglen on the Malheur NWR; at Old Eden Reservoir, in Wyoming; and at several sites in the Lahontan Valley, Nevada (table 18). Eared grebes nest in colonies on open, freshwater lakes, pools, or river backwaters. They generally lay eggs in June and use emergent vegetation for building their nests. The growth of the emergent vegetation needed for nesting material probably accounts for the later nesting season in this species, which may result in adults spending more time on the breeding grounds (presumably more time to accumulate local breeding ground contaminants) before laying eggs. Mean clutch size ranged from 2.53 to 3.90 eggs. As with black-necked stilts, the eared grebe also nests in unstable habitats, and nesting success was highly variable (range 0% success at Old Eden Reservoir [1988] to 100% success at Boca Lake [1987]). High winds can cause nests in open water to sink (e.g., East Alkali Lake [1987]), and mammalian predation can cause severe losses (e.g., mink [*Mustela vision*] at Old Eden Reservoir [1988]).

Snowy egrets and great blue herons (*Ardea herodias*) were studied in the Lahontan Valley in 1988. Both species nested in bulrush/cattail marshes. The herons nested earlier than the egrets, but Mayfield estimates showed few nests with eggs that hatched for either species (18.9% and 15.4%, respectively) (table 19).

Hatching success in the field was indeed variable during our studies in the arid West. Different habitat conditions from location to location seemed most responsible for the variability. Therefore, hatch success was of limited use for interpreting residue concentrations in eggs; however, the information is extremely useful in furthering our understanding of the biology of waterbirds that live in these fluctuating environments.

Hatching Success in the Incubator (Ducks).— Eggs collected in the field and placed in the incubator ranged from fresh eggs (no hen incubation) to nearly full-term incubation. Based upon previous experience with incubators, egg hatchability in the incubator was anticipated to depend on the number of days the eggs were incubated by the hen in the natural nest. Therefore, eggs placed in the incubator were divided into nine 3-day categories of hen incubation to evaluate this possible relationship (table 20). Duck eggs placed into incubators from all locations were used in this evaluation because a pattern independent of collection location was anticipated. Fresh game farm mallard eggs were incubated as a quality control check of the incubators in 1988 and 1989.

Duck eggs placed in incubators were divided into six categories of hen incubation for statistical analyses (0-2, 3-5, 6-8, 9-11, 12-14, and 15 days) (see table 20). Hatching success was significantly different among hen incubation categories for all study areas combined (x^2 = 69.65, 5 d.f. P<0.001). Furthermore, duck eggs with 0-2 days of hen incubation hatched at a significantly lower rate than expected (x^2 = 47.31, 1 d.f. P <0.001), while all other hen incubation categories hatched at rates higher than expected. The fact that fresh game farm mallard eggs (with little or no contaminants) hatched at a similar (61%), but significantly lower, rate than wild eggs with 0-2 days of incubation (71%) (x^2 = 5.21, 1 d.f. P = 0.02), and much lower than other wild eggs with longer incubation times by hens (90 to 100% when evaluating 3-26 days), strongly indicates an "incubator effect" on hatchability (i.e., fresh eggs hatched at a rate lower than eggs incubated by hens in the field for 3 days). Apparently, hens at the start of incubation provide something that incubators cannot mimic! Thus, hatch data for eggs placed in incubators with differing amounts of hen incubation need to be evaluated as two separate datasets (i.e., those with 0-2 days hen incubation [lower hatch success] and those with 3 or more days of hen incubation [higher hatch success]).

Data above indicate that egg hatchability depends on the egg incubation stage at the time of collection; however, to further document the above relationship, residue concentrations in eggs needed to be statistically tested (0-2 days of incubation by hen vs. 3-26 days of incubation by hen) to determine if egg residue concentrations were independent of the number of days incubated by the hen. We anticipated that egg concentrations of selenium, mercury, and boron, on a dry weight basis, would be independent of days incubated by hens. Selenium concentrations (geometric means) in duck eggs were independent of (0-2 vs. 3-26) days incubated by the hen at Malheur NWR in 1987 (1.14 vs. 1.00 ppm, P = 0.52), Lahontan Valley in 1987 (1.16 vs. 1.35 ppm, P = 0.18), Lahontan Valley in 1988 (1.34 vs. 1.53 ppm, P = 0.11), Seedskadee NWR in 1988 (1.83 vs. 2.29 ppm, P = 0.47), and Benton Lake NWR in 1989 (2.17 vs. 2.88 ppm, P = 0.08). Thus, selenium concentrations in eggs were not related to the stage of incubation at the time of collection. Mercury was evaluated at Malheur NWR in 1987 (0.24 vs. 0.18 ppm, P = 0.33) and Lahontan Valley in 1987 (0.35 vs. 0.18 ppm, P = 0.05) and 1988 (1.16 vs. 1.43 ppm, P = 0.44). Mercury concentrations in eggs were independent of days incubated by the hen in the field, except at Lahontan Valley in 1987. Boron concentrations were also independent of days incubated by the hen at both Malheur NWR in 1987 (1.82 vs. 2.25 ppm, P = 0.38) and the Lahontan Valley in 1987 (2.42 vs. 2.29 ppm, P = 0.73). Boron was not analyzed at Lahontan Valley in 1988. At Benton Lake NWR and Freezeout GMA in 1989, only 9 of 84 eggs contained boron concentrations above the 1.50-ppm detection limit; and in Wyoming and Utah, in 1988, only 23 of 218 eggs contained boron concentrations above the 2.00-ppm detection limit. The later two data sets, with higher detection limits, were not used in this analysis. The three elements of concern (selenium, mercury, and boron) showed either no

Table 19.—Summary of nesting information for the snowy egret and great blue heron in Lahontan Valley, 1988

Species/location	Eggs collected	Egg development[1]	Clutch size (n)	Apparent nest success (n)	Mayfield estimate: Daily survival rate (95% CI)	Mayfield estimate: Nest success
Snowy egret						
Canvasback Club	May 19-June 1	1-2	2.75 (20)	23.5% (17)	0.9302 (0.8913-0.9691)	18.9%[2]
Great blue heron						
Carson Lake	April 16-27	1-2	3.05 (20)	38.5% (13)	0.9330 (0.8858-0.9803)	15.4%[3]

[1] At time of egg collection: most fresh to early incubation = 1, most a week or more into incubation = 2, most late in incubation = 3.

[2] Used 23-day exposure period for Mayfield calculation.
[3] Used 27-day exposure period for Mayfield calculation.

Table 20.—Hatchability of duck eggs placed in incubators at Benton Lake NWR, Malheur NWR, Seedskadee NWR, and Lahontan Valley study areas, 1987-89

Study area	Control[2] n[3]	Control[2] %	0 - 2 n	0 - 2 %	3 - 5 n	3 - 5 %	6 - 8 n	6 - 8 %	9 - 11 n	9 - 11 %	12 - 14 n	12 - 14 %	15 - 17 n	15 - 17 %	18 - 20 n	18 - 20 %	21 - 23 n	21 - 23 %	24 -26 n	24 -26 %	Total n	Total %
Benton Lake NWR 1989[4]	59	85	28	71	50	98	88	93	56	95	38	97	32	97	18	100	6	67	2	100	318	93
Seedskadee NWR 1988[5]	54	59	16	56	24	83	16	88	16	100	12	83	4	100	6	100	8	88	0	--	102	84
Lahontan Valley 1988	108	49	30	80	12	83	30	83	18	89	2	50	2	100	6	100	6	100	0	--	106	81
Lahontan Valley 1987	0	--	100	75	18	89	16	94	16	94	10	100	0	--	0	--	14	100	0	--	174	82
Malheur NWR 1987	0	--	46	67	12	92	8	88	12	100	6	100	12	100	2	100	4	100	4	100	106	83
Total	221	61	220	71	116	90	158	90	118	95	68	94	50	98	32	100	38	92	6	100	806	83

Column groups 0 - 2 through 24 -26: Number of days incubated by hen before placement in incubator[1]

[1] All species of duck eggs combined.
[2] Fresh game farm mallard eggs.
[3] n = number of eggs placed in incubator, includes two eggs from each wild nest; % = percent of eggs hatched.
[4] Also includes eggs from Freezeout Lake, GMA.
[5] Also includes eggs from western Wyoming and northern Utah.

significant change in concentrations in relation to days incubated in the field by the hen before collection, or a statistically significant, but biologically insignificant, decrease of 0.17 ppm of mercury in the Lahontan Valley in 1987. Therefore, the conclusion is that the higher failure rate for eggs with the least incubation by hens (0-2 days in table 20) was independent of egg residue concentrations. The significantly lower success of fresh eggs (game farm mallards) and of wild eggs with 2 or fewer days of hen incubation is termed, as mentioned earlier, an "incubator effect." Hens incubate eggs the first 2 days in a manner not replicated by our incubator.

Our initial objective was to evaluate hatchability of the two eggs placed in the incubator from each nest (0 hatch, 1 hatch, 2 hatch) in relation to residue concentrations in the sample egg from that nest. Now, we have two data sets for analyzing the effects of contaminants on hatching success of eggs placed in the incubator: (1) those eggs with 0-2 days of incubation in the field by the hen (71% of eggs hatched); and (2) those eggs with 3 or more days of incubation in the field by the hen (93% of eggs hatched). Our approach was to score the two eggs placed in the incubator from each clutch as a 0,1, or 2, depending on how many eggs hatched. The success or failure of the incubator eggs, in relation to contaminants, was evaluated in a manner similar to days incubated by hens in the field (table 20). Both selenium and boron concentrations were divided into four residue categories (0-1.5 ppm, 1.51-5 ppm, 5.01-10 ppm, 10.01 ppm), and mercury into four different categories (0-0.25 ppm, 0.26-1 ppm, 1.01-2 ppm, 2.01 ppm). Categories were dictated by frequency distributions of residue concentrations (attempt to obtain similar sample sizes in first two categories) and perceived critical residue concentrations in bird eggs (highest category).

Selenium concentrations in eggs incubated by the hen for 2 days or less showed no significant differences between residue concentration groups and egg hatchability, although there were no selenium concentrations 10.01 ppm (table 21). Eggs incubated by the hen 3-26 days included eggs with 10.01 ppm selenium, and hatchability was significantly lower than expected in the highest group (table 21). The 14 eggs with 10.01 ppm selenium included 4 cinnamon teal (Stewart Lake, WMA, Utah), 2 redhead (Stewart Lake WMA, Utah), and 8 gadwall (2 at Ouray NWR and 6 at Benton Lake NWR).

Mercury and boron concentrations found in duck eggs were not significantly related to egg hatchability (tables 22 and 23).

Discussion

The NIWQP was designed to identify the nature and extent of water quality problems induced by irrigation drainage that might exist in the Western United States. Not all of the NIWQP study areas were selected because of potential selenium contamination; e.g., Malheur NWR was selected primarily because of organochlorine pesticide contamination, and the Lahontan Valley was selected primarily because of mercury and boron contamination.

Selenium

Although selenium was not the primary contaminant of concern at all locations, all eggs collected during this study were analyzed for selenium. Eggs collected at or near western wildlife refuges showed variability in selenium concentrations among species, refuges, and sites within refuges (table 11). The year-to-year

Table 21.—Selenium concentrations (ppm, dw) in duck eggs and hatching success in the incubator (all locations combined)

	Hen incubated 0-2 days[1]			Hen incubated 3-26 days[2]		
Category	Eggs hatched	Eggs failed	Total	Eggs hatched	Eggs failed	Total
0-1.5 ppm	112 (78%)	32 (22%)	144	176 (91%)	18 (9%)	194
1.51-5 ppm	66 (73%)	24 (27%)	90	296 (95%)	16 (5%)	312
5.01-10 ppm	0	0	0	46 (96%)	2 (4%)	48
10.01 ppm	0	0	0	11 (79%)	3 (21%)	14
Total	178 (76%)	56 (24%)	234	529 (93%)	9 (7%)	568

[1] χ^2 = 0.60, 1 d.f. (P = 0.44). Note, 6 eggs (5.01-10 ppm) were combined with the (1.51-5 ppm) group.
[2] χ^2 = 8.43, 3 d.f. (P = 0.04). Eggs in group 10.01 ppm (χ^2 = 4.64, 1 d.f., P<0.05) failed at a higher rate than expected.

Table 22.—Mercury concentrations (ppm, dw) in duck eggs and hatching success in the incubator (all locations combined)

	Hens incubated 0-2 days[1]			Hens incubated 3-26 days[2]		
Category	Eggs hatched	Eggs failed	Total	Eggs hatched	Eggs failed	Total
0-0.25 ppm	68 (69%)	30 (31%)	98	111 (90%)	13 (10%)	124
0.26-1 ppm	70 (78%)	20 (22%)	90	55 (89%)	7 (11%)	62
1.01-2 ppm	34 (85%)	6 (15%)	40	18 (82%)	4 (18%)	22
2.01-9.53 ppm	20 (77%)	6 (23%)	26	33 (92%)	3 (8%)	36
Total	192 (76%)	62 (24%)	254	217 (89%)	27 (11%)	244

[1] χ^2 = 4.22, 3 d.f. (P = 0.24).
[2] χ^2 = 1.45, 3 d.f. (P = 0.69).

Table 23.—Boron concentrations (ppm, dw) in duck eggs and hatching success in the incubator (all locations combined)

	Hen incubated 0-2 days[1]			Hen incubated 3-26 days[2]		
Category	Eggs hatched	Eggs failed	Total	Eggs hatched	Eggs failed	Total
0-1.5 ppm	41 (68%)	19 (32%)	60	158 (98%)	4 (2%)	162
1.51-5 ppm	55 (72%)	21 (28%)	76	86 (91%)	8 (9%)	94
5.01-10 ppm	18 (69%)	8 (31%)	26	13 (93%)	1 (7%)	14
Total	114 (70%)	48 (30%)	162	257 (95%)	13 (5%)	270

[1] χ^2 = 0.28, 2 d.f., (P = 0.87).
[2] χ^2 = 4.91, 2 d.f., (P = 0.09).

fluctuations in both selenium and mercury concentrations in eggs (tables 11,12) were initially somewhat unexpected. However, the study areas were all like oases in relatively dry environments and subject to highly variable conditions (from drought to floods). This study was conducted during good to high water conditions, and the findings may reflect only those conditions. Samples collected throughout a water cycle would be useful. In addition to the amount of selenium in soils, water availability (including the drying and reflooding cycles) and the amount of drainwater annually entering the wetlands probably account for much of the local variability in selenium concentrations in bird eggs, including the year-to-year fluctuations. Species diets probably account for much of the species variability at given locations, although the eared grebe spends the longest time in the nesting area before egg laying (waiting for emergent vegetation to grow for nest construction) and consistently had the highest selenium concentrations in its eggs. Presumably, the longer the birds eat a selenium enriched diet, the higher the selenium concentrations in their eggs; however, that simple logic may not necessarily be true. For example, Heinz (1993) reported a rapid accumulation of selenium in eggs of captive mallards. Selenium concentrations in eggs peaked in about 2 weeks on the selenium diet. Although Heinz (1993) reported a rapid accumulation of selenium in the eggs of captive mallards, the speed at which selenium accumulates and plateaus in wild birds, such as grebes and their eggs, has not been studied. Henny and Herron (1989) reported white-faced ibis nesting at Carson Lake in 1985 had significantly lower selenium concentrations in their eggs laid in April (3.29 ppm) than in May (5.40 ppm). However, in 1986, at the same site, no significant difference was reported for the same time periods (2.95 vs. 2.77 ppm). Length of breeding grounds residency each year was not known for the ibis in the above examples. Time spent in the breeding area cannot be totally eliminated as a factor contributing to high selenium concentrations in eared grebe eggs, but eared grebes, like other grebes, have a unique trait of eating their own feathers. Masses of feathers are commonly found in grebe stomachs (Martin et al., 1951), and these feathers have been oiled by the uropygial (preen) gland. The uropygial gland appears to be an additional pathway for grebes to eliminate selenium (see Goede and de Bruin, 1984; 1986). However, ingestion of these feathers causes grebes to recycle selenium.

Skorupa and Ohlendorf (1991) reported 3 ppm to be approximately the 90th-percentile value for geometric mean selenium concentrations in samples of eggs from selenium-normal sampling sites for various species of waterbirds. By assuming that < 3 ppm of selenium represents reference area means for waterbirds, we can quickly evaluate the selenium findings for eggs reported in this study (table 24). We further evaluated selenium effects by determining the percentages of eggs above published threshold levels for selenium-induced inviability of eggs. Skorupa (1998, personal communication) reported the EC_{50} (50% effect concentration) for overt teratogenesis was 30 ppm for dabbling ducks, compared to 58 and 105 ppm for black-necked stilts and American avocets, respectively. Skorupa noted that these comparative results suggest that ducks may be roughly twice as sensitive as stilts to selenium-induced embryo toxicity. The EC_{01} for overt embryo teratogenesis was predicted at 15 ppm for dabbling ducks, 14 ppm for stilts, and 41 ppm for avocets. However, selenium-induced inviability of eggs (not teratogenic effects) occurs for stilts at much lower selenium concentrations (i.e., between 6 and 7 ppm), which implies that the upper boundary for safe exposure levels for individual stilt eggs (embryos) is 6 ppm.

Table 24.—A comparison of selenium concentrations (ppm, dw) in eggs for species, locations, and years in this study with geometric means of egg residues 3 ppm selenium (above background); and incidence in individual eggs of selenium 6 ppm, and 10 ppm

	Ducks					Eared grebes					Other waterbirds				
	Means		Individual eggs			Means		Individual eggs			Means		Individual eggs		
	# Means[1]	# 3 ppm	# Eggs	# 6 ppm	# 10 ppm	# Means	# 3 ppm	# Eggs	# 6 ppm	# 10 ppm	# Means	# 3 ppm	# Eggs	# 6 ppm	# 10 ppm
Lahontan Valley, 1986-88															
Carson Lake	13	0	104	0	0	1	0	11	0	0	7	0	90	0	0
Sheckler Reservoir	2	0	13	0	0						1	0	7	0	0
Humboldt/Toulon	1	1	7	0	0						2	1	16	0	0
S-Line Reservoir	2	0	15	1	0						3	1	8	0	0
Lead Lake	7	0	52	0	0	2	2	34	0	0	7	0	77	0	0
Foxtail Lake	3	0	8	0	0	1	1	10	0	0	1	0	7	0	0
Stillwater Point Reservoir			1	0	0	1	1	3	1	0	1	0	6	0	0
Tule Lake	5	0	35	0	0	1	1	9	0	0	5	1	53	0	0
Massie/Desert Gun Club	1	0	2	0	0						1	1	4	2	1
Totals	34	1 (2.9%)	237	1 (0.4%)	0	6	5 (83.3%)	67	1 (1.5%)	0	28	4 (14.3%)	268	2 (0.7%)	1 (0.4%)
Malheur NWR, 1986-87															
Malheur Lake	10	0	61	0	0	1	0	10	0	0	6	0	58	0	0
Harney Lake	7	0	33	0	0						4	0	50	0	0
Totals	17	0	94	0	0	1	0	10	0	0	10	0	108	0	0
Western Wyoming, 1988															
Willis Ranch, Bear River	2	0	11	0	0						2	0	32	0	0
Seedskadee NWR	4	0	34	0	0						2	0	23	1	0
Big Sandy River	1	1	5	0	0						1	0	2	0	0
Old Eden Reservoir	2	0	5	0	0	1	0	24	0	0	4	1	30	1	1
Ocean Lake, Riverton	1	0	2	0	0						3	1	37	3	0
Totals	10	1 (10%)	57	0	0	1	0	24	0	0	12	2 (16.7%)	124	5 (4.0%)	1 (0.8%)
Northern Utah, 1988															
Ouray NWR	3	3	15	5	3										
Stewart Lake	2	2	5	4	3										
Totals	5	5 (100%)	20	9 (45%)	6 (30%)										
Benton Lake NWR, 1989															
Unit 1	3	2	15	4	0										
Unit 2	5	1	25	5	2										
Unit 3	4	1	22	5	1										
Unit 4A	4	1	21	3	0										
Unit 4C	5	3	30	2	0	1	1	10	3	0	1	0	3	0	0
Unit 5/6	4	1	26	0	0										
Totals	25	9 (36%)	139	19 (13.7%)	3 (2.2%)	1	1 (100%)	10	3 (30%)	0	1	0	3	0	0
Freezeout Lake GMA, 1989	4	0	27	0	0										

[1] When only one egg was collected and analyzed for a species or location, the record was not used for means (no means could be calculated).

Throughout this paper, results show that nesting success was highly variable among locations, years, and species. This variability occurred even though mean selenium concentrations were within a relatively narrow range. For example, hatching success at stilt nests varied from year to year at Harney Lake (1986, 1987) and Malheur Lake (1986, 1987)—21.6%, 62.9%, 100%, and 32.1%—in spite of small changes in selenium concentrations—geometric means—of 0.97, 1.90, not available, and 1.35 ppm. Nest predation and varying nesting habitat conditions (from suitable to extremely poor) were believed to be responsible for the wide range of nesting success observed in the arid West. Therefore, it was not possible to relate success of individual waterbird nests to egg residues from that nest; published literature was relied upon to interpret selenium concentrations observed in eggs. The duck eggs placed in incubators for hatching were notable exceptions. The incubator eliminated the habitat and predator variables. In this study, hatching duck eggs in the incubator, we used >10 ppm selenium as the upper category to determine if hatchability significantly decreased in eggs in relation to selenium. This concentration was chosen because the value was already reported in the literature as an adverse effect concentration for hatchability of game farm mallard eggs (Hoffman and Heinz, 1988; Heinz et al., 1989; and Heinz, 1996). See Skorupa (1999) for additional information. Although relatively few duck eggs in the study contained >10 ppm selenium, their hatchability was lower than lesser contaminated eggs (table 21). Therefore, in this discussion, four ways have been chosen to present egg selenium findings by location, species, and year: (1) occurrence of selenium means considered above background (3.0 ppm); (2) percentage incidence of eggs with 6 ppm selenium (lower hatchability threshold for stilts); (3) percentage incidence of eggs with 10 ppm selenium (lower hatchability threshold for ducks); and (4) incidence of teratogenesis (if observed). Actually, the percentage of individual eggs with 6 ppm and 10 ppm selenium were both shown for all species because the relative sensitivity to selenium for most species was unknown.

Occurrence of Selenium.—Hoffman et al., (1990) reported no surface-water concentrations of selenium (in areas influenced by irrigation drainwater) in and around Stillwater WMA in 1986-87 that exceeded baseline concentrations or Federal and State criteria for the protection of aquatic life or the propagation of wildlife. Rowe (1989) further reported that all surface-water concentrations of dissolved selenium were in the range of <1 to 3 micrograms per liter (µg/L). However, Hoffman et al., (1990) reported selenium that exceeded the values for bottom sediment and biota. Of the duck eggs sampled at the various locations in the Lahontan Valley (table 24), only 1 of 34 (2.9%) selenium means exceeded the 3-ppm background criterion. The lone exception was a small series of cinnamon teal eggs (geometric mean was 4.56 ppm) from Humboldt/Toulon (table 1), which technically is outside the Lahontan Valley. Single eggs of the other four duck species, that were collected at Humboldt/Toulon also contained elevated selenium (3.73 to 5.47 ppm) (table 1). The eared grebe eggs exceeded 3 ppm selenium at 5 of 6 (83.3%) locations in the Lahontan Valley. The lone exception was Carson Lake in 1986. The eared grebes exceeded the background mean at Lead Lake (twice), Foxtail Lake, Stillwater Point Reservoir, and Tule Lake, which are all located on the Stillwater WMA. A few other waterbird species from the Lahontan Valley showed mean selenium concentrations above 3 ppm (4 of 28 = 14.3%). These included black-necked stilts (again at Humboldt/Toulon) together with great blue herons (S-Line Reservoir and Massie/Desert Gun Club) and snowy egrets (Tule Lake). Hallock and Hallock (1993: table 17) also reported individual bird eggs from the Lahontan Valley with > 3 ppm selenium (apparently in 1988). We found that the eared grebe most consistently contained elevated selenium, and it was found nesting at many sites within the valley. Therefore, it is a logical candidate for future selenium monitoring efforts.

All species nesting at Humboldt/Toulon required further investigation because most elevated selenium concentrations were found in the limited number of eggs sampled there in 1987. Seiler and Tuttle (1997) collected additional American coot eggs and additional American avocet (*Recurvirostra americana*) eggs at Humboldt/Toulon in 1988 and 1996. Selenium concentrations in American coot eggs in 1988 (the geometric mean was 2.89 ppm, n = 17), and 1996 (the geometric mean was 4.22 ppm, n = 7) were higher than the 2.33 ppm we found in 1987, but American avocets contained even higher concentrations in 1996 (the geometric mean was 8.19 ppm, n = 7). The variability of selenium concentrations in eggs, shown above for coots (and the variability of mercury concentrations that will be shown later), prompts our concern about year-to-year fluctuations in eggs.

The ducks, eared grebes, and other waterbirds nesting at Malheur NWR in 1986 and 1987 (both Malheur Lake and Harney Lake and vicinity) had no geometric mean selenium concentrations in eggs above the 3-ppm background value we used.

Studies at various locations in western Wyoming in 1988 resulted in only 1 of 10 (10%) selenium means for ducks above 3 ppm. The one instance was a series of three mallard eggs (3.95 ppm) from the Big Sandy River near Seedskadee NWR. Two other duck eggs from the same area also contained elevated selenium concentrations (4.0 and 5.5 ppm). Stephens and Waddell (1998) reported large Tertiary Age deposits occurring in the Big Sandy River drainage where selenium concentrations in water have been as high as 5µg/L near Seedskadee NWR. A slightly higher incidence of elevated selenium means in eggs was found in the other waterbirds (2 of 12 = 16.7%). These included double-crested cormorants at Ocean Lake, near Riverton, and black-crowned night-herons at Old Eden Reservoir. No ducks or other waterbirds at Seedskadee NWR contained geometric mean selenium concentrations above 3 ppm.

The few duck eggs collected in northern Utah at Ouray NWR and Stewart Lake in 1988 all contained elevated selenium, and 5 of 5 means (100%) were above 3 ppm; several eggs contained >10 ppm. Stephens and Waddell (1998) reported geometric mean selenium concentrations of 54.7 ppm in bird eggs from the Roadside Ponds at Ouray NWR. This exceeded concentrations at which reproduction and survival were seriously affected (Skorupa and Ohlendorf, 1991). Stephens and Waddell (1998) reported selenium concentrations in 26 of 49 waterbird eggs from Stewart Lake that exceeded 8 ppm, which is associated with reproductive impairment in populations of some species. Also, they reported deformities consistent with selenium toxicosis in redhead and teal embryos.

The large lake at Benton Lake NWR was divided into six units. Water flows from Unit 1 down to Unit 6. Seeps were found along the lake from agricultural activities on the higher ground above the lake. Few species, other than ducks, were studied near the lake, but selenium means for eggs from 9 of 25 (36%) series of duck eggs contained more than 3 ppm selenium. The gadwall, which is a late nester and perhaps spends more time on the breeding grounds in this more northern area before laying eggs, consistently had the highest selenium concentrations (mean exceeded 3 ppm in all six units). Lesser scaup (another late nester) exceeded the 3-ppm background in Unit 1 and

Unit 4C, and mallards exceeded the 3-ppm background in Unit 4C. Eared grebes nested in Unit 4C, and their eggs also exceeded 3 ppm selenium. Freezeout Lake GMA is located about 30 km from Benton Lake, and none of the eggs of the four duck species contained mean selenium concentrations above 3 ppm. However, the gadwall was not one of the four species studied at Freezeout Lake.

Adverse Effects of Selenium.—The effects of selenium on egg hatchability and abnormalities were of primary concern in this study. The incidence of individual eggs with 6 ppm selenium (Skorupa, 1998), the incidence of eggs with 10 ppm selenium (table 24), and the incidence of teratogenic effects were evaluated. The black-necked stilt was the most selenium sensitive species studied by Skorupa (1998). Therefore, the 6-ppm criterion was considered the most sensitive upper boundary of safe exposure levels for eggs (embryos). In evaluating stilt eggs in this study, we found none with selenium concentrations above 6 ppm. The 10-ppm selenium criterion was based upon Heinz (1996). Our incubator studies with duck eggs supported the findings of Heinz and earlier studies by Skorupa and Ohlendorf (1991).

Individual duck eggs from the Lahontan Valley seldom (0.4%) had selenium concentrations 6 ppm (table 24). The only exception was one mallard egg at S-Line Reservoir. No duck eggs from Malheur NWR or western Wyoming contained selenium 6 ppm selenium. In contrast, 45% of the duck eggs from Ouray NWR and Stewart Lake contained 6 ppm selenium, and duck eggs from Benton Lake were intermediate (13.7%). Species of ducks at Ouray NWR and Stewart Lake with eggs containing 6 ppm selenium included two mallards, two cinnamon teal, two redheads, one gadwall, one northern shoveler (*Anas clypeata*), and one northern pintail. At Benton Lake, species with eggs containing 6 ppm selenium included 14 gadwall, 2 mallards, 2 northern pintail, and 1 lesser scaup. The 10-ppm selenium concentration, which more logically relates to duck hatchability, was not found in any individual duck eggs from the Lahontan Valley, Malheur NWR, or western Wyoming. However, 30% of the duck eggs from Ouray NWR and Stewart Lake (one cinnamon teal, one redhead, one mallard, one gadwall, and one northern pintail) and 2.2% of the duck eggs (three gadwall) from Benton Lake contained 10 ppm selenium.

Ducklings that hatched in the incubator and eggs that did not hatch (but were at least one-half developed) in the incubator were evaluated for abnormalities (table 25). Thus, at most, two eggs were evaluated from each duck nest sampled. No abnormalities were found in ducklings or duck embryos from the Lahontan Valley, Malheur NWR, western Wyoming, or Ouray NWR and Stewart Lake that were hatched or incubated in the incubator. However, a very small percentage (2 of 303 = 0.66%) of ducklings or embryos from Benton Lake NWR had abnormalities. A lesser scaup embryo (failed to hatch) had edema on the back of the head and neck, and a northern pintail embryo had a lower mandible 6 millimeters shorter than the upper, both feet greatly reduced in size, and each middle toe missing. However, selenium (2.54 and 2.60 ppm) concentrations were low in each egg, boron was below detection limits, and mercury was not analyzed. The cause of the abnormalities is unknown and may be a randomly occurring defect. The expected incidence of major external malformations in hatchlings of uncontaminated wild populations of aquatic birds and in embryos of laboratory incubated mallard eggs is usually less than 1% (Pomeroy, 1962; Gilbertson et al., 1976; and Hoffman, 1978).

Table 25.—Observed abnormalities of incubator-hatched ducklings and unhatched eggs (two eggs per clutch were placed in the incubator to determine hatchability and to evaluate abnormalities)

	Lahontan Valley, 1987	Lahontan Valley, 1988	Malheur NWR, 1987	Wyoming, 1988	Utah, 1988	Montana, 1989
Number hatched in incubator	150	84	92	62	20	292
Number of abnormalities	0	0	0	0	0	0
Number unhatched in incubator	44	24	20	67[1]	14[1]	18
Number of eggs ½ developed	26	7	11	20	6	11
Total eggs hatched or ½ development in incubator	176	91	103	82	26	303
Number of abnormalities (%)	0	0	0	0	0	2 (0.66)

[1] Includes eggs in incubator when temperature control failed and eggs overheated, but were still useful for abnormality evaluation.

Salvaged duck eggs and other waterbird eggs were also evaluated for abnormalities, and the incidence was reported on a nest basis (irrespective of how many eggs were evaluated from each nest) (table 26). Again, no duck eggs had abnormalities from the Lahontan Valley, Malheur NWR, or western Wyoming. However, one mallard egg from the entrance road pond at Ouray NWR contained a grossly deformed embryo with a missing lower mandible and deformed feet, which is typical of selenium-induced teratogenesis. An egg from the same clutch contained 63 ppm selenium, 0.10 ppm mercury, and 0.56 ppm boron. The salvaged duck eggs from Benton Lake NWR included one deformed embryo (1 of 148 = 0.68%), which yielded a nearly identical percentage to that found in the incubator eggs (0.66%). The deformed embryo was a gadwall with two sets of bills and an exposed brain. The feet and wings were normal. No egg was analyzed from the clutch for contaminants.

Individual eared grebe eggs seldom contained 6 ppm selenium (1.5%) in the Lahontan Valley and did not contain 6 ppm selenium at Malheur NWR or Old Eden Reservoir. The only other site sampled was Benton Lake, where 30% of the eared grebe eggs contained 6 ppm selenium. None of the eared grebe eggs collected in this study contained 10 ppm selenium. The eggs of other waterbirds from the Lahontan Valley, as with ducks at the same location, seldom (0.7%) contained 6 ppm selenium. The exceptions were two great blue heron eggs from Massie/Desert Gun Club. No other waterbird eggs at Malheur NWR contained 6 ppm selenium, but 4.0% of the eggs collected in western Wyoming contained 6 ppm selenium. The Wyoming eggs included one American coot at Seedskadee NWR, one black-crowned night-heron at Old Eden Reservoir, and two American coots and one double-crested cormorant from Ocean Lake. Only two other waterbird eggs contained 10 ppm selenium (one great blue heron at Massie/Desert Gun Club and one black-crowned night-heron at Old Eden Reservoir).

Of all waterbird eggs that were not from ducks, only one deformity was recorded (table 26). The embryo was from a Canada goose egg collected at S-Line Reservoir in the Lahontan Valley in 1988 (S-Line Reservoir is part of the water supply system rather than the drainage system). One eye was missing and the other was rudimentary. The embryo was three-quarters developed, but contained low amounts of selenium (0.82 ppm), mercury (0.27 ppm), and boron (3.46 ppm).

In conclusion, duck eggs were affected by selenium at Stewart Lake and at Ouray NWR and marginally affected at Benton Lake NWR. Eared

Table 26.—Observed abnormalities of salvaged eggs from successful, abandoned, and depredated duck and other waterbird nests

	Lahontan Valley, 1986	Lahontan Valley, 1987	Lahontan Valley, 1988	Malheur NWR, 1986	Malheur NWR, 1987	Wyoming, 1988	Utah, 1988	Montana, 1989
Ducks								
Number nests with eggs collected [1]	104	159	28	60	60	25	1	235
Number nests with eggs ½ developed	29	12	1	13	13	7	1	148
Number nests with abnormalities (%)	0	0	0	0	0	0	1 (100)	1 (0.68)
Black-necked stilts								
Number nests with eggs collected	50	46	44	23	33	2		
Number nests with eggs ½ developed	2	1	0	6	4	0		
Number nests with abnormalities (%)	0	0	0	0	0	0		
Eared grebes								
Number nests with eggs collected	47	17	32		21	25		19
Number nests with eggs ½ developed	18	8	0		19	0		14
Number nests with abnormalities (%)	0	0	0		0	0		0
American coots								
Number nests with eggs collected	63	43	27	25	27	49		
Number nests with eggs ½ developed	24	24	23	12	18	31		
Number nests with abnormalities (%)	0	0	0	0	0	0		
White-faced ibis								
Number nests with eggs collected					10	48		
Number nests with eggs ½ developed					0	23		
Number nests with abnormalities (%)					0	0		
Black-crowned night-heron								
Number nests with eggs collected						33		
Number nests with eggs ½ developed						1		
Number nests with abnormalities (%)						0		

Table 26.—Observed abnormalities of salvaged eggs from successful, abandoned, and depredated duck and other waterbird nests (concluded)

	Lahontan Valley, 1986	Lahontan Valley, 1987	Lahontan Valley, 1988	Malheur NWR, 1986	Malheur NWR, 1987	Wyoming, 1988	Utah, 1988	Montana, 1989
Double-crested cormorant								
Number nests with eggs collected						25		
Number nests with eggs ½ developed						5		
Number nests with abnormalities (%)						0		
Canada goose								
Number nests with eggs collected			7			26		
Number nests with eggs ½ developed			2			4		
Number nests with abnormalities (%)			1 (50)			0		
Great blue heron								
Number nests with eggs collected			20					
Number nests with eggs ½ developed			6					
Number nests with abnormalities (%)			0					
Snowy egret								
Number nests with eggs collected			29					
Number nests with eggs ½ developed			2					
Number nests with abnormalities (%)			0					

[1] Intact eggs collected from active nests or salvaged from successful, abandoned, and depredated nests. Eggs from each nest examined for development, with development of ½ development used for deformity determination. Each nest counted as one observation no matter the number of eggs collected from the nest.

grebes contained selenium above background in the Lahontan Valley and at Benton Lake NWR, but the effects depend on the species sensitivity. If the eared grebes are as sensitive as black-necked stilts, adverse effects could be occurring in both the Lahontan Valley (minor) and Benton Lake NWR (more severe). If their sensitivity to selenium is more like ducks, no adverse effects would be anticipated at either location. The Canada goose deformity at S-Line Reservoir in the Lahontan Valley was from an egg with low selenium concentrations. Other waterbird species, including great blue herons at Massie/Desert Gun Club and black-crowned night-herons at Old Eden Reservoir, may have been affected by selenium. No other waterbirds were sampled at Utah sites, and only a few were sampled at Benton Lake NWR.

Mercury

Mercury was evaluated in waterbird eggs from the Lahontan Valley, Malheur NWR, western Wyoming, and northern Utah (table 27). To our knowledge, no background mean concentration for mercury appears in the literature. In fact, the concept of "background level" is probably not realistic for mercury because it could vary considerably from location to location. However, it is used here as harmless levels that are found in areas where man's activities have not increased the amount of mercury in the environment. Although the value should not be construed as rigid or fixed, for descriptive purpose we use a geometric mean of 0.50 ppm in eggs as background, and most means reported were below 0.50 ppm.

Vermeer (1971) evaluated numerous aquatic bird eggs in the Prairie Provinces of Canada in 1968 and 1969 and reported that early nesters (before mercury seed treatment), which included mallards and Canada geese, laid eggs with mercury concentrations 0.50 ppm. The later nesters had elevated mercury concentrations, presumably from mercury seed treatments. We further evaluated potential mercury effects by determining the percentages of eggs above published threshold levels for mercury-induced inviability in eggs. Newton and Haas (1998) reported that merlin (*Falco columbarius*) productivity declined in clutches where mercury exceeded 3 ppm. Fimreite (1971) reported similar findings for ring-necked pheasants (*Phasianus colchicus*). Heinz (1979) reported behavioral changes in mallard ducklings produced from eggs with about 0.80 ppm mercury (ww), which converts to about 3 ppm (dw). Heinz (1979) also reported more eggs laid outside the nestbox and fewer 1-week-old ducklings produced than in the control population. Therefore, we have chosen to show the incidence of eggs with 3 ppm as the potential for adverse effects on eggs based upon our review of the literature.

The duck eggs in the incubators provided no statistical evidence of reduced hatching success when mercury concentrations were reported above 2 ppm (table 22). However, the literature implies that > 3 ppm mercury is needed to reduce productivity. Therefore, the 10 clutches that had eggs with >3 ppm mercury were evaluated separately. The 6 clutches (12 eggs) incubated 2 days or less in the field included 7 eggs that hatched (58%) and 5 eggs that failed, which was not significantly different (X^2 = 2.03, 1 d.f., P = 0.154) from the 185 eggs that hatched (76%) and 57 eggs that failed with 3.00 ppm mercury. Similarly, the 4 clutches (8 eggs) incubated in the field for 3-26 days included 7 eggs that hatched (88%) and 1 egg that failed, which was not significantly different (X^2 = 0.02, 1 d.f., P = 0.895) from the 210 eggs that hatched (89%) and 26 eggs that failed with 3.00 ppm mercury.

Table 27.—A comparison of mercury concentrations (ppm, dw) in eggs for species, locations, and years in this study with geometric means of egg residues 0.50 ppm (above background); and incidence in individual eggs of mercury 3.0 ppm

	Ducks				Eared grebes				Other waterbirds			
	Means		Individual eggs		Means		Individual eggs		Means		Individual eggs	
	# Means[1]	# 0.50 ppm	# Eggs	# 3.0 ppm	# Means	# 0.50 ppm	# Eggs	# 3.0 ppm	# Means	# 0.50 ppm	# Eggs	# 3.0 ppm
Lahontan Valley, NV 1986-88												
Carson Lake	13	6	104	3	1	1	11	0	7	7	90	22
Sheckler Reservoir	2	1	13	0					1	0	7	0
Humboldt/Toulon	1	0	7	0					2	0	16	0
S-Line Reservoir	2	1	15	0					3	2	8	4
Lead Lake	7	3	52	9	2	2	34	0	7	6	77	2
Foxtail Lake	3	1	8	0	1	1	10	0	1	1	7	0
Stillwater Point Reservoir			1	0	1	1	3	0	1	1	6	0
Tule Lake	5	2	35	1	1	1	9	0	5	5	52	7
Massie/Desert Gun Club	1	0	2	0					1	1	4	1
Totals	34	14 (41.2%)	237	13 (5.5%)	6	6 (100%)	67	0	28	23 (82.1%)	267	36 (13.5%)
Malheur NWR, OR 1986-87												
Malheur Lake	7	0	49	0	1	0	10	0	6	1	65	1
Harney Lake	5	1	24	0					4	1	38	0
Totals	12	1 (8.3%)	73	0	1	0	10	0	10	2 (20%)	103	1 (1.0%)
Western Wyoming, 1988												
Willis Ranch, Bear River	2	0	11	0					2	0	32	0
Seedskadee NWR	4	1	34	0					2	0	23	0
Big Sandy River	1	0	5	0					1	0	2	0
Old Eden Reservoir	2	0	5	0	1	0	24	0	4	0	30	0
Ocean Lake, Riverton	1	0	2	0					3	1	37	1
Totals	10	1 (10%)	57	0	1	0	24	0	12	1 (8.3%)	124	1 (0.8%)
Northern Utah, 1988												
Ouray NWR	3	0	15	0								
Stewart Lake	2	0	5	0								
Totals	5	0	20	0								

[1] When only one egg was collected and analyzed for a species or location, the record was not used for means (no means could be calculated).

Duck eggs from the Lahontan Valley regularly (41.2%) had mean mercury concentrations above background (0.50 ppm), and elevated mercury was seldom found at Malheur NWR, western Wyoming, and never found in northern Utah (table 27). However, perhaps more important, the incidence of individual duck eggs with 3 ppm mercury was 5.5% in the Lahontan Valley, and no duck eggs with 3 ppm mercury were detected at Malheur NWR, western Wyoming, and northern Utah. Species of ducks with eggs containing 3 ppm mercury in the Lahontan Valley included gadwall (three at Lead Lake, one at Tule Lake), mallards (four at Lead Lake), cinnamon teal (two at Lead Lake, two at Carson Lake), and ruddy duck (one at Carson Lake).

Eared grebes from the Lahontan Valley consistently laid eggs with mean mercury concentrations (6 of 6) above background (0.50 ppm), but no individual eggs contained 3 ppm. Mean mercury concentrations at the other sites with eared grebes sampled for mercury (Malheur Lake and Old Eden Reservoir) were below background with no eggs containing 3 ppm mercury.

The other waterbird eggs from Lahontan Valley showed a higher percentage of means (82.1%) above background than ducks, as well as a higher percentage (13.5%) of individual eggs with 3 ppm mercury. Species and numbers with individual eggs containing 3 ppm mercury in the Lahontan Valley included black-necked stilts (18 at Carson Lake, 3 at Tule Lake, 1 at Lead Lake), great blue herons (3 at Carson Lake, 4 at S-Line Reservoir, 1 at Massie/Desert Gun Club), snowy egrets (4 at Tule Lake), and American coots (one at Carson Lake, 1 at Lead Lake). At Malheur NWR (2 of 10) and in western Wyoming (1 of 12), means were above background, but only 1.0% of the individual eggs at Malheur NWR and 0.8% of the eggs in western Wyoming had 3.0 ppm mercury. Species with individual eggs containing 3.0 ppm mercury included a northern harrier (Malheur NWR) and a double-crested cormorant (Ocean Lake).

It is of special interest that, in 1987, American coot eggs collected at Humboldt/Toulon contained a geometric mean of 0.19 ppm mercury (table 2), and in 1988 contained similar concentrations (0.17 ppm, n = 17); however, in 1996, the eggs collected contained much higher concentrations (3.19 ppm, n = 7) (Seiler and Tuttle, 1997). Mercury is an issue of concern in the Lahontan Valley, and the severity of this issue (based on egg concentrations) varies tremendously from species to species, location to location, and, especially, year to year. Only two eggs collected outside the Lahontan Valley during this study contained mercury concentrations 3.0 ppm.

Boron

Boron was evaluated in waterbird eggs from the Lahontan Valley in 1987 and Malheur NWR in 1986 and 1987 (table 3, table 6). Boron was evaluated with higher detection limits in Wyoming and Utah in 1988 and Benton Lake NWR in 1989. Stanley et al. (1996) reported that mallards fed a diet of 450 ppm boron (as boric acid), which contained about 10% water, produced eggs with an arithmetic mean of 22 ppm boron. Egg fertility and hatchability did not differ significantly from control eggs. Also, no adverse effects on duckling weight or duckling growth were noted, compared to controls in the laboratory study. They also reported that mallards fed a diet of 900 ppm boron laid eggs with an arithmetic mean of 38 ppm boron. Egg fertility and hatchability were significantly reduced from controls (e.g., hatching success 66% and reduced to 38%) with the higher boron concentrations.

Stanley et al. (1996) cited Moore et al. (1989) and pointed out that reported maximum field collected boron concentrations in eggs were only 6 ppm in mallards and northern pintails and 5 ppm in gadwalls. None of the geometric means for boron at Malheur NWR were >5 ppm, except for seven American coot eggs from Harney Lake (mean 6.40 ppm). Of the Malheur NWR eggs analyzed in 1986 and 1987, 6 of 44 (13.6%) from Harney Lake contained 10 ppm boron (American coot 11, 11 ppm; black-necked stilt 11, 11, 14 ppm; gadwall 12 ppm); however, 0 of 117 from Malheur Lake contained 10 ppm boron. Eggs from the Lahontan Valley in 1987 included five means >5 ppm boron, and four of the five means were American coots (S-Line Reservoir, 12.74 ppm; Lead Lake, 8.36 ppm; Carson Lake, 5.93 ppm; and Humboldt-Toulon, 5.52 ppm). The fifth mean was for gadwall at Carson Lake (6.71 ppm). Coots eat primarily submerged aquatic vegetation, except in the summer (Martin et al., 1951), and the amount of boron absorbed by plants varies considerably from species to species and depends on the stage of growth (Butterwick et al., 1989). Therefore, the vegetation diet may be a factor in the higher boron concentrations in coot eggs. Only 10 of 220 eggs (4.5%) from the Lahontan Valley contained 10 ppm boron, including: 7 American coots (4 at Lead Lake, 10, 11, 15, 22 ppm; S-Line Reservoir, 56 ppm; Foxtail Lake, 12 ppm; Carson Lake, 14 ppm), 2 redheads (Carson Lake 10, 10 ppm), and 1 mallard (Carson Lake, 10 ppm).

In Wyoming and Utah, boron was also evaluated in our studies in 1988, using a relatively high detection limit of 2 ppm. No eggs contained >12 ppm boron, and only 23 of 218 eggs were above the detection limit. Boron was also evaluated in 1989 at Benton Lake NWR and Freezeout Lake GMA, using a detection limit of 1.50 ppm. Only 9 of 84 eggs contained boron concentrations above the detection limit (maximum 3.82 ppm).

Only one egg (56 ppm) among those collected (all species) contained boron above the arithmetic mean of 22 ppm (normal production) or 38 ppm (reduced production), determined from controlled laboratory studies with mallards. The American coot nest, which apparently contained the highest boron concentration reported from a wild bird egg, was found at S-Line Reservoir in the Lahontan Valley in 1987. The nest was successful and contained one hatched young coot and two pipped eggs during the last nest visit. Although S-Line Reservoir is a water supply system rather than the drainage system for the Lahontan Valley, it must be recognized that birds fly around and may range widely on the breeding grounds (and accumulate contaminants) before choosing a nesting site. The highest boron concentration previously reported during the National Irrigation Water Quality Program was 41 ppm (a lesser scaup egg collected at Freezeout Lake, Montana, in 1991) (Lambing et al., 1994).

Organochlorine Pesticides

Long-term patterns of organochlorine concentrations in eggs of black-crowned night-herons, snowy egrets, white-faced ibis, and black-necked stilts at several locations became apparent from data collected during this study and in earlier years. DDE was the primary OC of concern for the species evaluated.

DDE in black-crowned night-heron eggs (geometric means) from Malheur NWR decreased between 1979 and 1980 (4.70 vs.2.73 ppm), and findings for Ruby Lake NWR, in northeastern Nevada, were similar (8.21 vs. 4.13 ppm). Black-crowned night-heron eggs from the Lahontan Valley showed a decrease in DDE that continued from 1980 to 1988 to 1996 (5.08 vs. 2.43 vs. 0.99 ppm). Thus, a consistent pattern of decreasing DDE concentrations was noted throughout the sampled sites in the Intermountain West. Also, the incidence of DDE above 8 ppm (the critical egg concentration for adverse effects on nesting success) had diminished to zero in the Lahontan Valley by 1996.

Geometric mean DDE concentrations in snowy egret eggs in Malheur NWR in 1981 (1.70 ppm) were similar to concentrations in the Lahontan Valley in 1981, 1982, 1983, and 1988 (1.43, 1.91, 0.62, and 1.91 ppm, respectively). Findholt (1984) reported geometric mean DDE concentrations in 1979 of 4.8 and 4.2 ppm at Blackfoot Reservoir and Minidoka NWR in Idaho. The two Idaho locations (combined) included 9 of 19 eggs (47%) with 5 ppm DDE, which was determined to be the critical DDE concentration to adversely affect snowy egret reproductive success (Findholt 1984, Henny et al., 1985). The long-term dataset from the Lahontan Valley showed no apparent DDE trend between 1981 and 1988, and the continued presence of 5 ppm DDE in some eggs. Therefore, the evidence based on residue concentrations in eggs indicates that DDE was still negatively influencing reproductive success of snowy egrets in the Lahontan Valley in 1988. The observed snowy egret nesting success in the Lahontan Valley in 1988 was extremely low (table 19).

White-faced ibis were the subject of a detailed study in the Lahontan Valley in 1985-86, and they were monitored earlier, in 1980-83. DDE concentrations in eggs 4 ppm negatively influenced productivity. Between 1980 and 1986, an estimated 36% of the ibis population was laying eggs above the critical DDE concentration. More recently, in 1988 and 1996, a similar 39 and 45% of the eggs from the Lahontan Valley contained 4 ppm DDE; thus DDE continues to negatively influence white-faced ibis productivity.

Ten black-necked stilt eggs were analyzed for OC pesticides in the Lahontan Valley in 1988 to compare with the 10 eggs collected annually in the valley between 1980 and 1983. DDE decreased in the eggs (from a geometric mean of 3.26 to 1.20 ppm) between 1980 and 1988. Because DDE did not result in any change in eggshell thickness, it is doubtful that DDE was influencing reproductive success in the black-necked stilt population during this study in the Lahontan Valley.

The eared grebe was evaluated for OC pesticides at Lead Lake in the Lahontan Valley and at Old Eden Reservoir in western Wyoming in 1988. DDE was extremely low at both locations (geometric means 0.19 and 0.23 ppm, respectively), and other pesticides were seldom detected.

In summary, black-crowned night-heron and black-necked stilt eggs showed remarkable decreases in DDE during the 1980s, and, in the case of the black-crowned night-heron (with eggs sampled in the 1990s), DDE continued to decline. In contrast, white-faced ibis eggs have shown no evidence of decreasing DDE from 1980 to 1996 in the Lahontan Valley. Henny and Herron (1989) have shown that DDE was not accumulated in the Lahontan Valley breeding grounds. Therefore, it must have been accumulated elsewhere—presumably in the wintering grounds. Satellite telemetry research is in progress to determine the source of the DDE accumulated by the white-face ibis. The DDE pattern for the snowy egret was similar to the white-faced ibis, with no evidence that DDE decreased between 1981 and 1988 in the Lahontan Valley. About 20-21% of the snowy egret eggs contained 5 ppm DDE—a concentration that negatively influences reproduction. Eared grebes contained extremely low DDE concentrations at both sites studied.

Summary and Conclusions

In 1986-89, nesting waterbirds were studied at five localities in the Western United States. National Wildlife Refuges are key landholdings at each study site. The NWRs included Malheur, in Oregon; Stillwater, in Nevada; Seedskadee, in Wyoming; Ouray, in Utah; and Benton Lake, in Montana. Adjacent, off-refuge sites were also sampled at most of the locations and included state WMAs. Usually, one egg was collected from each bird nest for residue analyses. However, after the first year, three eggs were taken from each duck nest: one for residue analyses and two for placement in an incubator. The incubator eliminated the habitat and predator variables and permitted an evaluation of hatching success and the presence of abnormalities in relation to contaminant concentrations in the sample egg collected for residue analysis. Nesting success of the other waterbirds (eggs not placed in incubators) was also quite variable among locations and years. Therefore, the potential negative effects of contaminants on the other waterbirds was estimated by comparing residue concentrations with published background and critical concentrations in eggs. This approach resulted in a determination of the frequency distribution of egg concentrations and the percentage of eggs at the various locations above perceived critical concentrations. Hatching success for the nests sampled was presented to provide some understanding of the success of birds nesting in these generally unstable environments. Then, when abnormalities were detected, the frequency was also presented. This multifaceted approach was used to reach conclusions and evaluate the consistency of the information. The year-to-year fluctuations in residue concentrations of selenium and mercury cause concern in interpreting the 1986-89 data collected during this study. It is true that the concentrations represent the years of the study, but they may not be as useful as originally anticipated for predicting future concentrations at the study areas. More study is needed to relate egg concentrations to climatic (e.g., flooding, drought, and reflooding) and other factors so that useful predictions can be made. It may be that trace element related reproductive problems for given species may occur only at certain places and in perhaps only a few years out of a decade or a water cycle.

Lahontan Valley, Nevada

Duck eggs from 1986-88 were seldom found to contain geometric mean selenium concentrations above background (3 ppm). Other waterbird species showed a higher incidence of mean selenium concentrations above 3 ppm, and eared grebe eggs consistently contained the highest selenium concentrations. The higher selenium concentrations possibly resulted from the eared grebe's long wait in the area before an adequate overwater nesting substrate became available, although other possible factors are discussed. Individual duck eggs (0.4%) and other waterbird eggs (0.7%) seldom contained 6 ppm selenium, which is the lowest known effect level reported (for black-necked stilts) for reduced reproductive success. The degree to which nesting success of various species may be impaired by selenium toxicity was believed low in 1986-88, but nesting success depends upon each species' sensitivity to selenium, which was usually unknown. Data were also presented for the incidence of selenium concentrations in individual eggs 10 ppm (a value from the published literature and supported by our incubator studies of wild duck eggs). No duck eggs from the Lahontan Valley had 10 ppm selenium and no ducklings or duck embryos with abnormalities were found in the Lahontan Valley during this study. A question of concern about selenium and other contaminants in the Lahontan Valley, as well as elsewhere, is the year-to-year variability in egg concentrations. This can, perhaps, best be shown with selenium in American coot eggs from Humboldt/Toulon, where, in 1987, eggs contained a geometric mean of 2.33 ppm. In 1988, the geometric mean was a similar 2.89 ppm; but in 1996, it increased to 4.22 ppm (see Seiler and Tuttle, 1997). The changes most likely reflect changes in water quality and water availability, and the 1988 data were similar to the 1987 data collected during this study, but the 1996 data imply that data collected during our study (9 years earlier) may differ considerably from what will be found in the future. The factors driving the availability and bioaccumulation of selenium in birds from the arid West are not well understood.

Mercury was evaluated in the same general way as selenium, but with different background (geometric mean, 0.50 ppm) and individual critical egg concentrations (3 ppm). Duck eggs (41.2%) and other waterbird eggs (82.1%) consistently had mean mercury concentrations greater than background. The incidence of duck eggs with 3 ppm mercury was 5.5%, and other waterbird eggs was 13.5% in the Lahontan Valley during this study. As with selenium, mean mercury concentrations in eggs fluctuated from year to year (e.g., Humboldt/Toulon for American coots in 1987, 0.19 ppm; 1988, 0.17 ppm; but in 1996, 3.19 ppm. These numbers reflect a relatively safe situation from mercury in 1987 and 1988, but a potentially damaging situation from mercury in 1996. Again, it is critical to understand factors responsible for these fluctuations. Mercury is a concern in the Lahontan Valley, and the magnitude of the problem seems to vary from location to location and from year to year.

Laboratory studies in which boron was fed to mallards showed that eggs with an arithmetic mean of 22 ppm boron hatched as well as control eggs, and that eggs with an arithmetic mean of 38 ppm boron showed reduced hatching success. Only 10 of 220 eggs from the Lahontan Valley (4.5%) contained 10 ppm boron, and only 1 egg contained >22 ppm boron (an American coot from S-Line Reservoir with 56 ppm boron that successfully hatched at least 1 young). It is doubtful that boron was having an adverse effect on nesting success of any species during the study; but if it was, the most likely species affected was the American coot, which accounted for 7 of the 10 eggs with 10 ppm boron. The increased boron in coot eggs was probably related to the species' largely vegetarian diet.

Only one embryo abnormality was found in the Lahontan Valley, and it was a Canada goose embryo from S-Line Reservoir. The embryo had one eye missing, and the other eye was very small; however, it contained low concentrations of selenium (0.82 ppm), mercury (0.27 ppm), and boron (3.46 ppm). The cause of the deformity remains unknown.

Malheur NWR, Oregon

The ducks, eared grebes, and other waterbirds nesting at Malheur NWR contained generally low selenium concentrations in their eggs, and no geometric means above background (3 ppm). In addition, no individual duck or other waterbird eggs contained 6 ppm selenium.

Eggs from ducks, eared grebes, and other waterbirds at Malheur NWR seldom contained > 0.50 ppm (3 of 23 geometric means) mercury (cinnamon teal and black-necked stilt at Harney Lake and northern harrier at Malheur Lake), but only 1 of 186 eggs (0.5%) contained 3.0 ppm mercury (a northern harrier). Because of the ability of mercury to biomagnify up food chains, it was not unexpected that a raptor (the northern harrier) would have the highest mercury concentration at Malheur NWR.

Within Malheur NWR, only American coot eggs at Harney Lake had geometric means for boron above 5 ppm. As at Lahontan Valley, coot eggs again had some of the highest boron concentrations. Six of 44 eggs (13.6%) contained 10 ppm boron at Harney Lake, and none of 117 eggs from Malheur Lake contained 10 ppm boron. No egg contained boron above the known level of concern. No ducklings or embryos with abnormalities were found at Malheur NWR.

Western Wyoming

Ducks nesting in western Wyoming, including Seedskadee NWR, contained generally low selenium concentrations in their eggs and infrequently contained geometric mean concentrations 3.0 ppm. The lone exception (1 of 10) was mallards nesting along the Big Sandy River near Seedskadee NWR. Other waterbird species had a slightly higher incidence of elevated selenium, with 2 of 12 means 3.0 ppm (16.7%). The species included double-crested cormorants at Ocean Lake and black-crowned night-herons at Old Eden Reservoir. We found that 4.0% of the individual eggs collected in western Wyoming contained 6 ppm selenium. These included eggs from three coots, one black-crowned night-heron, and one double-crested cormorant. No abnormalities were found in western Wyoming. Only the eggs of black-crowned night-herons at Old Eden Reservoir, double-crested cormorants at Ocean Lake, and cinnamon teal at Seedskadee NWR contained mean mercury concentrations 0.50 ppm (background). None of the individual duck and eared grebe eggs, but 0.8% of the other waterbird eggs, contained 3.0 ppm mercury. The lone bird egg was a double-crested cormorant from Ocean Lake. We found no evidence of mercury being an important issue in western Wyoming study areas. Boron was analyzed in Wyoming and Utah with a detection limit of 2 ppm. No eggs contained >12 ppm, and few (23 of 218) were above the detection limit. Therefore, all eggs were below known boron effect concentrations.

Ouray NWR and Stewart Lake, Utah

The few duck eggs collected at Ouray NWR and Stewart Lake all contained mean selenium concentrations 3 ppm, and several individual eggs contained concentrations >10 ppm selenium. Of the 20 duck eggs collected, 9 (45%) contained 6 ppm selenium and 6 (30%) 10 ppm selenium. These findings are in agreement with other published findings for the two Utah sites. A mallard egg from the north roadside pond at Ouray NWR (same nest reported [but different egg collected] by Stephens and Waddell [1998]) contained 63 ppm selenium, and the embryo was grossly deformed. Clearly, selenium was a significant issue at both Utah sites in 1988.

Elevated mean mercury (0.50 ppm) concentrations in eggs were not found for any duck species, and none of the individual eggs contained 3 ppm. The low concentrations imply that mercury was not a problem for ducks. Only duck eggs were sampled in Utah.

Benton Lake NWR and Freezeout Lake GMA, Montana

Benton Lake was the focus of nesting studies that emphasized ducks. Duck eggs in all six units of the lake were studied, and 9 of 25 (36%) means were 3 ppm selenium. Gadwall consistently had the highest selenium concentrations. A study of ducks nesting at a seleniferous domestic wastewater disposal site near the city of Davis, California, also found that gadwall eggs consistently had the highest selenium concentrations (Mike Conner, City of Davis, personal communication). We found 13.7% of the duck eggs contained 6 ppm, and 2.2% of the duck eggs (3 gadwall) contained 10 ppm selenium. The 10-ppm critical concentration is generally accepted for duck eggs. Mallards nesting near seeps contained significantly higher selenium concentrations in eggs than mallards nesting away from seeps. Three duck embryo abnormalities were found, but they could not be clearly related to selenium. We estimate that the success of a small percentage of the duck eggs laid at Benton Lake NWR was negatively affected by selenium.

Eared grebes in Unit 4C at Benton Lake contained a mean of 5.65 ppm selenium, 3 of 10 eggs contained 6 ppm selenium, and none contained 10 ppm selenium. Because it is not known which, if either, of these toxic thresholds (6 ppm vs. 10 ppm) best applies to eared grebes, it is uncertain whether grebes were adversely affected. However, until an appropriate toxic threshold is determined for eared grebes, egg residues exceeding any of the established toxic thresholds for other taxa of birds warrant further attention. Freezeout Lake GMA, located about 30 km from Benton Lake NWR, had no mean selenium concentrations 3.0 ppm and no eggs (0 of 27) with selenium concentrations 6.0 ppm, although no gadwall eggs were sampled. The lack of gadwall studied at Freezeout Lake GMA is important because gadwall at Benton Lake NWR consistently had the highest selenium residues. However, the overall selenium means for all other duck species at Benton Lake NWR (all units combined) were higher than at Freezeout Lake GMA.

Mercury was not analyzed in eggs from Benton Lake NWR or Freezeout GMA. Boron was found at low concentrations at both Benton Lake and Freezeout Lake, and no eggs contained >3.82 ppm.

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Abbreviations and Acronyms

ANOVA	analysis of variance
DDE	dichlorodiphenyl dichloroethylene
DDT	dichlorodiphenyl trichloroethane
dw	dry weight
ETSRC	Environmental Trace Substances Research Center
ft	foot
g	gram
GMA	Game Management Area
ha	hectare
HCB	hexachlorobenzene
HLA	Hazelton Laboratories America, Inc.
ICP	inductively coupled plasma
km	kilometer
m	meter
mL	milliliter
mm	millimeter
MSCL	Mississippi State Chemical Laboratory
NIWQP	National Irrigation Water Quality Program
NWR	National Wildlife Refuge
OC	organochlorine
PACF	Patuxent Analytical Control Facility
PCB	polychlorinated biphenyls
ppm	part per million
PWRC	Patuxent Wildlife Research Center
Reclamation	Bureau of Reclamation
RTI	Research Triangle Institute
WMA	Wildlife Management Area
ww	wet weight
µg/L	microgram per liter

Photographs

Photo 1.—Bulrush marsh at Carson Lake, Nevada.

Photo 2.—Duck nesting habitat at Stillwater NWR, Nevada.

Photo 3.—Typical transitory nesting habitat of the black-necked stilt at Malheur NWR, Oregon.

Photo 4.—White-faced ibis nest in bulrush marsh at Willis Ranch/Bear River, Wyoming.

Photo 5.—Nesting colony of double-crested cormorants at Ocean Lake, Wyoming.

Photo 6.—Black-crowned night-heron nest at Old Eden Reservoir, Wyoming.

Photo 7.—Eared grebe nest at Stillwater NWR, Nevada. Eared grebes are late nesters, requiring emergent vegetation to construct their nests.

Photo 8.—Mitigation pond at Seedskadee NWR, Wyoming.

Photo 9.—Nest of a redhead duck at Malheur NWR, Oregon.

Photo 10.—Saline seep at Benton Lake NWR, Montana.

Photo 11.—Agricultural drain into Freezeout Lake GMA, Montana.

Photo 12.—Searching for waterbird nests at Willis Ranch/Bear River, Wyoming.


Photo 13.—North Roadside Pond at Ouray NWR, Utah.


Photo 14.—Bulrush marsh at Stewart Lake, Utah.

Photo 15.—Nesting habitat at Old Eden Reservoir, Wyoming, where American coot, black-crowned night-heron, and eared grebe nests were found.

Photo 16.—One of the upper ponds at Ocean Lake, Wyoming. Vegetation along the pond edge consisted of cattail and bulrush.


Photo 17.—Recently hatched northern harrier chicks from Malheur NWR, Oregon.


Photo 18.—Duck nesting habitat at Benton Lake NWR, Montana.